Water resources
Preservation and management
Agropolis International brings together institutions of research and higher education in Montpellier and Languedoc-Roussillon in partnership with local communities, companies and regional enterprises and in close cooperation with international institutions. This scientific community has one main objective—the economic and social development of Mediterranean and tropical regions.

Agropolis International is an international space open to all interested socioeconomic development stakeholders in fields associated with agriculture, food production, biodiversity, environment and rural societies.

Agropolis is an international campus devoted to agricultural and environmental sciences. There is significant potential for scientific and technological expertise: more than 2 200 scientists in over 80 research units in Montpellier and Languedoc-Roussillon, including 300 scientists conducting research in 60 countries.

Agropolis International is structured according to a broad range of research themes corresponding to the overall scientific, technological and economic issues of development:

- Agronomy, cultivated plants and cropping systems
- Animal production and health
- Biodiversity and Aquatic ecosystems
- Biodiversity and Land ecosystems
- Economics, societies and sustainable development
- Environmental technologies
- Food: nutritional and health concerns
- Genetic resources and integrative plant biology
- Grapevine and Wine, regional specific supply chain
- Host-vector-parasite interactions and infectious diseases
- Modelling, spatial information, biostatistics
- Water: resources and management

Agropolis International promotes the capitalisation and enhancement of knowledge, personnel training and technology transfer. It is a hub for visitors and international exchanges, while promoting initiatives based on multilateral and collective expertise and contributing to the scientific and technological knowledge needed for preparing development policies.
Water research expertise in Montpellier and Languedoc-Roussillon

Seven years after the first “Dossier d’Agropolis International” on the theme of “Water: resources and management”, it was time for giving an update in order to provide the large number of website visitors (about 120,000 downloads of the Dossier, French and English versions combined) with up-to-date information and developing visibility with evidence of the progress made by the Languedoc-Roussillon region’s scientific water community. Readers will also find an updated directory of research, technology transfer and higher education structures.

This Dossier thus presents 18 research units from Languedoc-Roussillon and Avignon, gathering more than 800 scientists, working fully or partially on hydrosystems, water quality and/or water resource management. Research units focused on lagoons and coastal zones are not presented here but in another Agropolis Dossier about “Aquatic Ecosystems” published in 2007. The Dossier also presents 10 international cooperation or valorisation structures or programmes, in which the regional water scientific community is highly involved. Finally, it also gives a list of 43 higher education diplomas, from 2 to 8 years postgraduate, proposed in the region and more or less tightly linked to the theme of water.

The re-edition of this Dossier in early 2012 is an opportunity to demonstrate the dynamism of the regional water scientific community on the occasion of the 6th World Water Forum held in Marseille, France (12-17 March 2012) and of the international water exhibition Hydrogaia in Montpellier (6-8 March 2012).

This is also the first Agropolis Dossier to be available in Spanish, in addition to the usual French and English versions.
In recent years, the Montpellier scientific community has continued its consolidation through a number of research projects (funded by the French National Research Agency, European Union 6th and 7th Framework Programmes, French “Investissements d’avenir” programmes, etc.) and educational projects (“Water” Master’s degree, Masters courses, etc.) it has co-ordinated and successfully accomplished. A selection of those projects is presented in this document.

Among these projects, the most emblematic success has no doubt been the involvement of businesses through the creation of a “Water” competitiveness cluster with an international scope. Its mission is to coordinate the actions the French “water” clusters from the three regions of Languedoc-Roussillon, Provence-Alpes-Côte d’Azur and Midi-Pyrénées. Its leadership is recognised to offer cooperation and development prospects to all water sector stakeholders. Another important success is the creation of three research and teaching Chairs: (i) the UNESCO-labelled Chair “Membrane sciences applied to the environment”, on water treatment by membrane processes, (ii) the “Water for All” Chair in partnership with the Suez-Environnement company, offering capacity building programmes for utility managers in the developing and emerging countries and (iii) the Chair “Risks analyses of emerging contaminants in aquatic environments” in partnership with the Veolia company, focused on organic contaminants in water.

The aim of the Dossiers d’Agropolis International is also to support the projects led by the Languedoc-Roussillon region’s scientific community. For the previous Dossier, the challenge was the organisation of the XIIIth World Water Congress in Montpellier in September 2008, which then favoured the settlement in 2010 of the executive board of the International Water Research Association (IWRA) on the Agropolis campus. The first stake of this Dossier is to give international visibility to the regional water scientific community on the occasion of the 6th World Water Forum, held in Marseilles, France, in March 2012.

This event has huge ambitions since its objectives are not only to take stock of the latest world-wide developments in water management and shared recommendations for achieving sustainable development, but also to provide solutions to many issues remaining unresolved and new challenges likely to arise. The regional scientific community, engaged in the event, provides its contribution.

Thierry Rieu (AgroParisTech, Centre de Montpellier)
The Sabai glacier and the Sabai Tsho lake in Nepal.
Water resources: identification, functioning, mobilisation
The latest UNESCO world report on water resources was already characterised by a rather alarming tone. For instance, it stipulated that "despite the vital dimension of water, this domain is plagued by a chronic lack of political attention, poor governance and insufficient investment", and that "action is urgently required to prevent a global crisis".

Yet, it is estimated today that global annual withdrawals amount to 3,800 billion m³, representing only 25% of useable resources. But such a relative abundance does not reflect the huge disparities in the geographic distribution of this vital resource. Indeed, some regions are already facing hydric stress (less than 500 m³/year/inhabitant), while others are hit by disasters caused by chronic overabundant rainfalls. Such inequalities raise all kinds of difficulties and challenges.

Given the global population growth, water demand increases by 64 billion m³ each year. Water needs are becoming increasingly high in relation to strategic decisions and associated commitments being taken in areas such as agriculture, economic development and energy production.

The disturbances induced by climate change also have an impact on the hydrological cycle. Indeed, in many regions of the world, the Intergovernmental Panel on Climate Change (IPCC) forecasts all point towards longer droughts and/or more frequent floods. Such disturbance further aggravates the degradation of ecosystems, already facing growing anthropogenic pressures.

From the health point of view, 80% of the diseases affecting developing countries are water-related. This is due to insufficient access to drinking water and lack of sanitation infrastructures, owing to both poor funding and poor political and strategic decisions.

This alarming water situation is further compounded by the general public's growing environmental concerns and international and global thinking about water issues. "Blue Gold" is slowly emerging as one of the most critical stakes of the 21st century, with the growing looming threat of "water wars".

Within such a context, it is more than ever important to control as completely as possible the resource, in order to feed the reflexion on how to better manage and govern water. It is therefore necessary to be able to locate, identify, evaluate and mobilise water resources. These are major stakes. They call for the analysis, understanding and modelling of all water cycle processes, be they natural or man-made.

The regional scientific community has the skills required to play a leading international role and to provide answers to some of the society's concerns. For this purpose, it has developed proven observation capabilities on which research is being based: the Universe Sciences Observatory OREME, the Environmental Research Observatories OMERE, AMMA-CATCH, OHMCV and H+, the KARST Observation system, etc. Recently, the regional scientific community has received significant equipment subsidies from the French Ministry of Research, thus reinforcing its position as a leader in the field of spatial information for environmental purposes.

The expertise of regional teams in the field of underground water has long received the highest acclaim, especially in the key area of karsts. This research field is particularly strategic for the Mediterranean coastal regions as these contain almost 60% of the water resources exploited.

The regional research community has become a reference for its research on surface water. Although the fundamental issue of the transformation of rain water into running water – and hence into a resource available in different forms (infiltration, runoff, storage) – is a core concern for hydrologists, numerous other issues are also addressed by the community. One such issue is the use of water in agriculture, deemed to be essential, especially within the Mediterranean context. The issue of floods, mainly considered from the viewpoint of extreme events (destructive floods and rainfalls), is another key topic to which many experts are devoted.

Finally, other approaches are future-driven. Using available climate scenarios based on varying environmental, economic and demographic hypotheses, these aim at assessing water resources.

Clearly, the region hosts a wide range of skills and expertise. These are all called on to tackle the challenges of tomorrow in terms of sustainable management of water resources, which is such a vital issue for the societies and every person in the world.

Éric Servat (UMR HSM)
Water resources: identification, functioning, mobilisation

**Main teams**

**UPR EAU/NRE**
Water: New resources and Economy (BRGM)
14 scientists
Director: Jean-Christophe Maréchal
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**UMR EMAH**
Mediterranean Environment and Agro-Hydrosystems Modelling (INRA, UAPV)
40 scientists
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**UMR GM**
Montpellier Geosciences (CNRS, UM2)
89 scientists
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**UMR HSM**
Montpellier HydroSciences (CNRS, IRD, UM1, UM2)
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Director: Éric Servat
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**UMR LGEI**
Industrial Environment Engineering Laboratory (EMI)
45 scientists
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**UMR LISAH**
Laboratory for the Study of Interactions between Soils, Agrosystems and HydroSystems (INRA, IRD, Montpellier SupAgro)
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**UMS OREME**
Mediterranean Environment Research Observatory (CNRS, IRD, UM2)
3 scientists sensu stricto + 6 linked units
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Biogeochemistry, extreme events, underground water and hydrological cycles
in Mediterranean and tropical regions

The Montpellier HydroSciences Joint Research Unit (JRU) – UMR HSM (CNRS, IRD, UM1, UM2) is devoted to research in water sciences covering a broad range of domains from biogeochemistry to extreme events, including underground water and the hydrological cycle.

HSM carries out most of its scientific activity in the Mediterranean and tropical regions, in four scientific fields:

- Biogeochemistry, contamination agents and health.
- Karsts and heterogeneous environments: hydrogeology, hydraulics and transfers.
- Climate, environmental changes and modelling of their impacts on water resources.
- Hydrological cycle mechanisms, surface-atmosphere transfers and interactions.

In addition, the laboratory develops four cross-disciplinary technical approaches: (a) hydrodynamic modelling and couplings; (b) hydrosphere tracers; (c) modelling methods: assimilation, spatialisation and sensitivity; (d) information systems.

HSM is highly involved in research-oriented training and education. The training courses provided by the laboratory attract French and foreign students alike (especially students from developing countries): “Water” Master’s degree, “Health Engineering” Master’s degree, “Water sciences and technologies” engineering degree of Polytech’Montpellier. Besides, the whole HSM staff is involved in training from the science degree to Ph.D. levels.

Much of its research being based on observation, the laboratory is a member of the Universe Sciences Observatory OREME (see page 13). It also participates to several observation systems (MEDYCIS, OHMVC, AMMA-CATCH, OMERÉ), while playing a leading role in the development of the KARST Observation System. In addition to its water chemistry and microbiology equipment, the laboratory have access to other major technical facilities: the large regional technical platform for the “analysis of trace elements in the environment” and the collective laboratory for the analysis of stable isotopes in water.

HSM strength relies on its involvement in a number of national and international projects, its extensive network of collaboration with research laboratories and institutions worldwide, giving the lab a high level of international recognition. HSM also works with public partners (DRE: Regional Directorate for the Environment, AFSSET: French Agency for Environmental and Occupational Health Safety, local authorities: communities of municipalities, joint basin organizations, etc.), private consultancy and engineering companies (SDEI, BioUV S.A., SOMEZ, etc.). HSM has also filed several patents, especially in metrology, and has developed "professional" software tools, particularly around data management. Besides, the study of organic contaminants is one of HSM’s fields of excellence. It has set up, in partnership with the company Veolia, a training and research chair devoted to the “Risks analyses in relation to emerging contaminants in aquatic environments”. Moreover, HSM is involved in the “Water” and “Local Vulnerability and Risk Management” competitiveness clusters.

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...continued on page 10
The Mediterranean basin is characterised by unevenly distributed and limited water resources as well as by increasing anthropogenic pressures. Hydro-climatic projections suggest a progressive diminution of the mean annual flows in this region, accompanied by more frequent and severe drought periods. Moreover, water demand has doubled since the nineteen fifties and is likely to continue to grow as irrigated surfaces increase and urban areas spread. Within the HSM JRU, the RESCUE-Med team focuses its research on the prospective evaluation of water resources under pressure of climate change and uses at different scales in the Mediterranean region.

As part of a current PhD and in partnership with the “Blue Plan”, the future availability of water resources is modelled at the regional scale according to various scenarios of climatic and water demand evolution, for agricultural and household purposes. A hydric stress indicator was developed, emphasising regional disparities concerning the capacity to meet various water needs at different periods in the past and future. Alternative scenarios, such as supply networks with improved efficiency, are being tested to assess the efficacy of adaptive strategies. The team also studies the impact of these changes on the water resources at more local scales. Hydrological modelling coupled with water uses is thus implemented in the river basins of Ebre (Spain) and Hérault (France). These research efforts seek to elaborate scenarios of climate change and water demand evolution adapted to these working scales. The objective is to assess the volumes and dynamics of flows, taking into account anthropogenic pressures (storage, withdrawals, consumption and transfers), in order to provide water resource managers with decision-making support tools.

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Water resources: identification, functioning, mobilisation

> WATER RESOURCES AND GLOBAL CHANGES

**SICMED: The evolution of Mediterranean anthro-ecosystems**

The Mediterranean region is one of the focal points of global changes. The region evolves swiftly under the effects of severe climatic and anthropogenic pressures, while the resources produced are already unable to meet the population needs. The current intense exploitation of resources aggravates social and environmental weaknesses and induces high stresses on the hydrological and biogeochemical cycles. Critical situations and conflicts of use are increasing in frequency and intensity. The quest for new ways of sustainable development calls for a deeper knowledge of anthro-ecosystem degradation, resilience, flexibility and rehabilitation factors.

Within this context, the SICMED programme (continental surfaces and interfaces in the Mediterranean) carries out research, training and transfer activities dedicated to the study of evolving Mediterranean rural and peri-urban anthro-ecosystems subjected to global change-induced stresses. It is one of the components of the MISTRALS (Mediterranean Integrated Studies at Regional And Local Scales) project, and for the last decade it has been developing a multi-disciplinary research project to study biophysical, technical and social mechanisms at work.

The programme pursues three objectives:

1. To identify and analyse the scientific locks preventing efficient forecasting of the evolution of the bio-hydro-geo-chemical processes subjected to current and future anthropogenic and climatic stresses;
2. To develop knowledge and tools for the rationalised management of the systems studied;
3. To transfer such knowledge and tools to decision makers and managers in the private and public sectors.

The SICMED programme is funded by IRSTEA, CNRS-INSU, INRA and IRD. It is based on a broad multilateral partnership involving scientific institutions and stakeholders representing various Mediterranean countries, but also other countries involved in research and development towards the Mediterranean region.

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More information on SICMED: www.sicmed.net
More information on Mistrals: www.mistrals-home.org

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**Other teams involved**

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- Presentation page 47

**UMR G-EAU**

Water Management, Stakeholders, Uses (AgroParisTech, IRSTEA, GEMAC-IAMM, CIRAD, IRD, Montpellier SupAgro)
- 75 scientists
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- Presentation page 40

**UMR ITAP**

Information – Technology – Environmental Analysis – Agricultural Processes (IRSTEA, Montpellier SupAgro)
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- Presentation page 28

**UMR TETIS**

Territories, Environment, Remote sensing and Spatial Information (AgroParisTech, CIRAD, IRSTEA)
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- Presentation page 46

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**Mass and energy transfers in porous, fractured and karstic aquifers**

The Montpellier Geosciences Joint Research Unit – UMR GM (CNRS, UM2) has developed a global approach to earth dynamics and their surface manifestations. This takes into account the couplings between the various layers including the hydrosphere. The objective is to gain a better understanding of the dynamic processes at different scales, and to bring this in line with societal expectations such as:

- Supply of non-energy resources (mineral and hydric);
- Energy choices for the future, from extending carbon-based reserves to developing new energy technologies (natural hydrogen, geothermal energy);
- Waste storage and confinement (downstream from the nuclear cycle, CO₂, mining wastes, etc.);
- Natural hazards (earthquakes, tsunamis, gravity hazards, floods, etc.);
- Environmental and climatic changes with high anthropogenic impact (coastline evolution, sea water intrusion in groundwater).

GM comprises five multidisciplinary teams working in three scientific fields:

- Geodynamics (“Lithosphere Dynamics” and “Mantle and Interface” teams)
- Reservoirs (“Basins” and “Porous Environment Transfers” teams)
- Risks (“Risks” team)

Research on water is undertaken by the “Porous Environment Transfers” and “Risks” teams. It concerns the characterisation and modelling of mass and energy transfers in porous, fractured and karstic aquifers. The main scientific challenges lie in the **in situ** measurement of these transfers, taking into account the heterogeneities controlling them at all scales. These research works target four objectives: the development of (1) instrumented sites (Majorca, Maguelone, Roussillon, Larzac and Lodève) dedicated to observation and experimentation, (2) devices allowing controlled dynamic experiments, (3) surface and bore hole...
hydrogeophysical measurement and monitoring systems and (4) specific digital tools allowing the integration of data obtained at different scales.

These research works are carried out in the framework of several projects supported by the French National Research Agency (MOHINI, GRAIN D’SEL, LINE, COLINER, and HYDROKARST-G2) and the SOERE H+ (long term observation and experimentation systems for environmental research in hydrogeology). GM is in charge of several SOERE H+ experimental sites around the Mediterranean region. GM is a member of the OREME Mediterranean Environment Research Observatory, being in charge of several observation tasks (SO-LTC, GPST2, GEK, Bore Hole Hydrogeophysics).

GM is involved in the large regional technical platform for the “analysis of trace elements in the environment”. It also houses equipments for the “Gravimetry” and “Experimentation” platforms of the National Institute for Universe Sciences (absolute gravimeter and EBSD SEM).

GM is also a part of a wide national and international cooperation network including countries and programmes from Europe (Marie-Curie, FP7 networks), the Mediterranean region (North Africa, Middle East), and all over the world (Taiwan, Japan, India, Australia, New-Zealand, Iran, Brazil, Mexico and the USA). GM collaborates with the private sector, namely via the creation of businesses by PhD students and for the funding of research contracts and theses. It belongs to the Geosciences cluster initiated in 2011 and involving key regional companies (Geoter, Cenote, imaGeau, Schlumberger, Fugro, Antea, Areva, Lafarge) and R&D and training organisations (GM, BRGM, EMA, CEFREM, HSM). A large number of these stakeholders are active in the field of water. ***

The OMERE observatory supports the study of global changes affecting the Mediterranean hydrosystems/agrosystems. It is located in an intermediate hydrological context, between arid and temperate environments, subjected to a wide range of hydrological processes stretching from severe drought events to extreme floods. The observatory also explores the social and human context, submitted to considerable and rapid changes (intensification of agricultural productions in favourable areas, abandonment of farmlands in less favourable zones, increased water withdrawals, hydro-agricultural or environmental planning, etc.). The various climate change scenarios elaborated by IPCC foresee major rainfall changes in these latitudes: less winter precipitations, more extreme rainfall events.

Given the peculiar situation of the Mediterranean region, the observatory has been collecting climatic, hydrological, sediment and solute flows in two catchment basins over the last two decades. These basins differ in terms of soils, hydro-agricultural developments, cultural practices and evolution dynamics: Roujan (France, mainly wine growing) and Kamech (Tunisia, polycrops-stock farming). The objectives of the observatory are as follows: i) to understand the impact of agricultural activities on mass flows in Mediterranean elementary catchment basins (hydrological regimes and balances, water resource allocation, erosion dynamics, evolution of water quality); ii) to assess the intensity and speed at which water and ground resources can change as a function of changing land use; iii) to support the development of modelling approaches for flows in agricultural environments, by bringing observation in line with modelling; iv) to supply scientific bases, references and diagnostic tools for the agro-environmental engineering of agricultural landscapes. The HSM JRU, the Tunis National Institute of Agronomy, the Tunisian National Institute of Rural Engineering, Water and Forestry, and the LISAH JRU are the four partners in charge of coordinating and managing OMERE. The Observatory is a member of the French catchment basin network*.

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> WATER RESOURCES AND GLOBAL CHANGES
OMERE: Mediterranean Observatory of Rural Environment and Water

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Instrumentation of the Roujan site (Hérault, France) as part of the OMERE observatory.
**The OpenFLUID platform: modelling and simulation of the spatial functioning of agricultural landscapes**

The spatio-temporal functioning of agricultural landscapes results from complex interactions between biophysical processes and human activities. Modelling the functioning of such systems and simulating their changes under the impact of climatic changes and anthropogenic pressures (pollution, development, changes in land use), involves taking into account all these interactions and coupling many processes/phenomena distributed in the area studied. In order to implement such modelling processes and run simulations based on these coupled models, the LISAH JRU has developed an advanced and generic software tool.

Thus, the OpenFLUID platform can provide a software environment to model and simulate the spatial functioning of agricultural landscapes. It allows models to be developed and implemented during simulations. These models are developed as plug-in software tools for OpenFLUID. Then they can be used to create coupled models adapted to (i) the modelling context, (ii) the simulation objectives and (iii) the data available. The simulations are based on digital representations of the landscapes studied. These include the geometries and properties of the actual landscape elements. OpenFLUID has been used for numerous projects and Ph.D. theses. It has been applied to Mediterranean and tropical environments, for the modelling of water and pollutant flows and erosion, especially under the impact of agricultural practices. OpenFLUID also provides software support for the development and implementation of the MHYDAS (distributed hydrological modelling of agro-systems) model, among others, as well as the digital representation of agricultural catchment basins, and the simulation of water and pollutant flows. OpenFLUID has a user graphic interface and can also be used in a command line (in a calculation cluster for example). It is an open-source, free licence software and can be downloaded from the OpenFLUID internet site.

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* www.umr-lisah.fr/openfluid

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**Analysis of the hydrological cycle for research, economic and industrial activities**

The **Industrial Environment Engineering Laboratory – UPR LGEI** – is an Internal Research Unit of Alès Engineering High School (École des Mines d’Alès, EMA), a national public institution reporting to the Ministry of Industry. Its research work covers a broad field of applications based on complementary disciplines: process engineering, analytical chemistry and metrology, microbiology, molecular biology, hydrology, hydrogeology, geomatics, geostatistical methods, computer sciences and modelling, simulation tools and decision support systems.

Water issues are addressed from several angles: control of disastrous impacts for a resilient environment; understanding and spatialisation of hydrological processes in catchment basins (modelling); diagnosis of the chemical and ecological quality of water and effluents; development of processes and process couplings for the treatment of water and effluents; integrated management of polluting flows (industrial environments, water resources) according to a "local ecology" type approach; geomatics and collective intelligence for decision support. These different levels of water cycle analysis make it possible to answer the questions raised not only by science, but also by economic and industrial stakeholders.

LGEI is part of the **Institut Carnot M.I.N.E.S.**, reflecting its privileged relationships with the economic sector. The laboratory is active in the “Water”, “Trimatie”, “Local Vulnerability and Risk Management” and "Eurobiomed" competitiveness clusters. It collaborates with academics and industrialists at national and international levels, participating and coordinating several European projects.

The laboratory hosts all the facilities needed in a chemistry lab (HPLC/MS/MS, GC/MS/MS, ICP, extractors, etc.), as well as a test hall for semi-industrial pilot scale experiments. Academic and industrial teams have access to these facilities through the regional technical platforms, including Ecotech LR (Eco-technologies for agro-bioprocesses).

Moreover, the hydrometric monitoring of experimental catchment basins is a fundamental research effort for understanding the processes underlying flash kinetics floods. This research started in 2001 in collaboration with the ESPACE-DEV, HSM and TETIS JRUs. Several experimental catchment basins in the Cevennes are currently being monitored. Thanks to the diversity of the experimental devices, research work has focused on developing imaging applied to river velocities and flow rates as well as “low cost” devices for extending and refining distributed hydrometric analyses.

* SWIFT: Screening Methods for Water Data Information in Support of the Implementation of the WFD.

KNAPPE: Knowledge and Need Assessment on Pharmaceutical Products in Environmental waters
Observation for a better understanding of the dynamics and facilitated management of water resources

The Mediterranean Environment Research Observatory Joint Service Unit – UMS OREME (CNRS, IRD, UM2) is dedicated to the study of the uncertainties and vulnerabilities of Mediterranean environments. OREME focuses on natural hazards, resources and the impact of global and anthropogenic changes on the living and inert Mediterranean area. Its aim is to identify such systems’ response mechanisms to natural and anthropogenic forcing.

OREME’s mission consists in collecting, integrating and sharing long-term observation data to understand the evolution of resources and environments. This data is also essential for developing explanatory and predictive models.

OREME closely works with public partners (universe and ecology sciences laboratories, information science laboratories, local authorities and State agencies) and private companies (especially IBM).

In the field of water, OREME collaborates with other JRUs in order to develop hydrologic observation systems. These range from the basin scale to the in situ bore-hole scale:

- Geodesic, gravimetric, geophysical/hydrogeophysical systematic bore-hole observation at all scales;
- Multi-scale observation system of flood dynamics and underground hydrodynamics of fractured and karstic systems;
- Observation system for the pollution and biological adaptability downstream from mining sites;
- Monitoring of the Languedoc coastline, interface between catchment basin and marine environment.

These observation systems – included in French and international networks – provide information on water resource dynamics, especially karstic aquifers. They also make it possible to monitor the quantity and quality of the resource downstream from the aquifers. Geophysical methods are used to monitor underground water movements and link aquifer supplies with their discharge. The aim here is to understand their hydrological cycles and analyse it both in terms of resource quantity and hydrological hazards, such as flash discharges.

The quantity and quality of the resource available at each utilisation site are the result of complex processes. Their assessment needs combining models of water storage, flow and physico-biochemical couplings occurring in the various compartments. Complex simulations are necessary to understand these conditions: real-time modelling of the state of the resource, its uses and their immediate effects. At the core of this process of study, the data collected, calculated or associated with uses must be processed within the “acquisition-refinement-processing-decision” continuum.

Thanks to its network of partnerships and its expertise, OREME intervenes at different stages of this continuum, especially during acquisition (sensor network management), storage, sharing (management of query standards and norms, management of metadata, web services, etc.) and decision support (detection of changes, information fusion, reasoning, user interactions, visualisation, recommendation, forecasting and real-time operations).

The water resource must be managed in such a way as to prevent or better manage crises. This is why resource modelling must give a picture as close as possible to the reality, so that risks can be analysed and the necessary decisions taken in real time. For this reason, a shift to operational decision support models is required. Indeed, to avoid having to carry out time-consuming exhaustive modelling, “basic” simulations, based on reliable data, has to be performed upstream. ***
Water resources: preservation and management

The Mediterranean Environment and Agro-Hydrosystem Modelling Joint Research Unit – UMR EMMAH (INRA Avignon, UAPV) is focused on impact analysis of global changes on water resources, agricultural production and their interactions at the local level (from the landscape to the production basin and the aquifer). The research works target five cross-disciplinary goals:

- Quantification of the impacts of global change on the interactions between surface biophysical processes (agricultural production and water cycle) and water resources, especially underground.
- Identification of landscape changes and their driving forces, based on a retrospective analysis that stretches over several decades.
- Understanding of the modifications induced by extreme climatic events (such as drought/heat wave) on the functioning of agro-ecosystems.
- Understanding and modelling the impacts of heavy rainfall on the hydrological and hydrochemical functioning of the ground-table system.
- Study of alternative irrigation techniques, such as the use of water downstream from waste water treatment plants, particularly regarding quantification of the risks associated with the presence of human pathogens in these treated waters.

EMMAH’s work is based on the utilisation of remote sensing and geophysical data, intensive observation of instrumented sites, laboratory measurements and methodological development to better understand and model the functioning of Mediterranean ecosystems. EMMAH has set up a monitoring system of several observation sites representative of different hydro-geological and agronomic contexts (Crau-Camargue region, karstic aquifers of the Fontaine de Vaucluse, Avignon peri-urban zone).

In addition, two sites are dedicated to the study of hydric flows into the atmosphere and the water table. EMMAH is also equipped to carry out biological measurements (biomass, foliar index, chlorophyll content, etc.), chemical analyses of water and soils (organic and mineral chemistry), water isotopic analyses (H\(^2\), C\(^{14}\), C\(^{13}/\)C\(^{12}\) ratio of dissolved carbon) and ground hydrodynamic properties. EMMAH also has access to the Rustrel (Vaucluse) low-disturbance underground laboratory in the karstic massif of Fontaine de Vaucluse, and to the INRA molecular biology lab in Avignon. It is also equipped with subsurface geophysical prospecting instruments (electrical tomography). The researchers develop mechanistic models for hydrosystem functioning. These integrate and spatialise the elementary models associated with the different processes, on the one hand, and include new modelling approaches that take into consideration the heterogeneities of the environment and processes at different scales, on the other hand.

The disciplinary expertise and techniques implemented cover hydrology, hydrogeology, soil and water geochemistry and microbiology, agronomy, remote sensing, geophysics, applied mathematics, the physics of waves in porous media, digital simulation, parallel calculation and signal processing.

EMMAH collaborates with the French academic world (INRA: French National Institute for Agronomic Research, CEA: French Nuclear and Alternative Energies Centre, CNRS: French National Centre for Scientific Research, Universities, etc.) and the international academic world (Sfax National School of Engineering, Tunisia; Spanish Institute for Sustainable Agriculture and Valencia University, Spain; Dutch National Aerospace Laboratory and University of Twente, Netherlands; Universities of Maryland and Boston, USA, etc.). Moreover, EMMAH also develops partnerships with French institutional or managerial bodies (Rhône-Méditerranée-Corse Water Agency, irrigators’ and farmers’ unions, joint organisations for the management of underground water resources) as well as private partners (Veolia, Suez Environnement, engineering offices, etc.).
At the crossroad of soil sciences, hydrology and agronomy: the functioning of cultivated landscapes

The Laboratory for the Study of Interactions between Soils, Agrosystems and Hydrosystems (LISAH) – UMR SupAgro (INRA, IRD, Montpellier SupAgro) studies the functioning of cultivated landscapes resulting from the interactions between i) the underlying soil, ii) the agrosystem that modifies the geometry of the landscape and iii) the hydrosystem that transfers water and other elements. It serves the following specific objectives:

- The development of knowledge on erosion, water and material transfers and the evolution of polluting substances (pesticides) in soils and cultivated catchment basins with respect to their spatial organisation and temporal evolution;
- The elaboration of tools for diagnosing and preventing the risks induced by human activities (cultivated environments) on hydrological regimes and the evolution of water and land resources;
- The definition of new modes of sustainable management for the rural environment;
- The training of students on the concepts and tools used to analyse and model the spatial organisation and the hydrology of cultivated environments.

LISAH combines expertise in soil science, hydrology, agronomy and spatialisation. Its structure is based on three research teams:

- Water and pollutants in cultivated catchment basins;
- Erosion and sediment transport in cultivated catchment basins;
- Spatial and dynamic structure of soils and cultivated landscapes.

LISAH especially focuses on wine growing in the Languedoc-Roussillon region and banana tree farming in the French Antilles, with the following objectives:

- Study of soils and water pollution by phytosanitary products;
- Analysis of the “soil-crop” system hydrological cycle at various scales, from the elementary (a few km²) to the resource (a few hundred km²) catchment basins;
- Development of digital soil mapping methods and information systems;
- Analysis of factors and processes of soil erosion and sediment transfer in catchment basins;
- Study of the influence of hydraulic works (ditches, banks, hill lakes) on the hydrological functioning of cultivated soil and catchment basins.

LISAH scientific approach is based on in situ hydrological studies and experiments, methodological research for the acquisition and processing of soil and landscape spatial data and development of distributed hydrological modelling approaches, taking into account the specific heterogeneities of rural landscapes. To this end, LISAH runs the Mediterranean Observatory of Rural Environment and Water (OMERE, see page 11). The laboratory analyses the impact of anthropogenic actions on the physical and chemical erosion of Mediterranean soils and on the quality of water. Moreover, since 2006, LISAH has been developing the simulation platform OpenFLUID (Software Environment for Modelling Fluxes in Landscapes, see page 12).

> FUNCTIONING OF COMPLEX AQUIFERS

Aquifers in bedrock regions: a water resource to be managed

Bedrock (granite, schist, gneiss, etc.) occupies large surface areas in Europe and France and elsewhere across the planet. The water resources they contain are used substantially in agricultural and economic development in the regions concerned. This is particularly true for emerging economies where the context is arid or semi-arid and access to water is limited.

The BRGM EAU/NRE research unit contributes to the development of knowledge on the genesis, geometry, hydraulic properties and functioning of bedrock aquifers. Significant progress has been made in this corpus of knowledge. More specifically, it has been demonstrated that climatic alteration processes significantly influence aquifer properties through the development of alteration profiles. Moving downwards, these are made up of (see figure on the right): loose alterites (coarse sand in granitic zones), characterised by low permeability and significant underground water storage capacities; a stratabound “cracked horizon”, 50 to 100-metres thick, also strongly influenced by alteration processes and to which the bedrock aquifer owes much of its permeability.

Numerous practical applications stem from these geological and hydrogeological concepts. One such application is regional mapping of underground water potentialities and the regionalisation of hydrodynamic parameters for modelling. Other applications concern water resource management tools for catchment basins. Indeed, such management is essential for intensive withdrawals for irrigation purposes. These applications also cover bore-hole layout techniques and methods leading to improved success rates for exploitable flow rates.

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Water resources preservation and management
Several researchers are involved in teaching for vocational training, for the "Water" Master's degree and others Master's and engineering courses related to water.

EAU/NRE has developed a strong partnership with the French-Indian Research Centre on Underground Water. This joint BRGM-NGRI (National Geophysical Research Institute) laboratory, based in Hyderabad in the south of India, has developed research on base aquifers in tropical regions using the SOERE (H+) observation system. The lab develops tools for managing aquifers that are severely impacted by agricultural practices (irrigation pumping, pollution) and by climate change.

EAU/NRE specifically develops applied research activities directed to local authorities, water agencies and industrialists. Several projects have led to the development of methodologies to study mineral water deposits and their industrial management (i.e. Nestlé Waters and Danone Eaux France). Moreover, EAU/NRE is involved in the “Water” competitiveness cluster.

Located in Montpellier on the Mediterranean shore, LISAH runs collaboration programmes with several Tunisian and Moroccan higher education, research and training institutions: Hassan II Agronomy and Veterinarian Institute in Rabat; National Institute of Research on Rural Engineering, Water and Forestry in Tunis; National Institute of Agronomy in Tunis; National Engineering School in Tunis, National Centre for Cartography and Remote Sensing. It also works in partnership with public and private stakeholders in the field of water and soil resource management.

Hydrogeologists and economists working on water resource management

The Water/New resources and Economy Internal Research Unit – UPR EAU/NRE – belongs to the BRGM Water Department. Its permanent staff comprises eight hydrologists and six economists whose research efforts focus on water resource management. EAU/NRE’s activities comprise two main scientific focuses:

- The development of alternative solutions to conventional water resources, that are suffering from increasing constraints, i.e. climate change, anthropogenic pressure, socio-economic evolution, urban growth, etc. The following topics are more specifically studied: (i) characterisation of the structure and functioning of complex aquifers (karst, fractured ground, volcanic environments) in order to assess their potentialities; (ii) development of modelling and decision support tools for managing these aquifers and forecasting impact of global changes; and (iii) development of active resource management methods (recycling of treated waste waters, artificial recharging of water-tables, inter-seasonal storage and controlled overexploitation).
- The development of economic approaches needed to evaluate water resource management scenarios at the basin scale. Research efforts focus on the economic evaluation of incentive programmes and resource management policies as a function of uses, the economic optimisation of resource management plans via cost-efficiency analyses, the weighting of benefits and drawbacks between economic development and environmental policies, the comparison of approaches (analysis of costs avoided), the contingent evaluation based on enquiries and the elaboration of medium and long-term water use scenarios (prospective analysis).

Several researchers are involved in teaching for vocational training, for the "Water" Master's degree and others Master's and engineering courses related to water.
Water resources: preservation and management

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The Mediterranean Karstic Aquifers: Complex Systems

Karstic aquifers contain a significant share of water resources in France (35% of the country), all the more in the Mediterranean region (> 50%). Their heterogeneity makes these zones complex (with voids varying in size from cracks of a few centimetres to sinkholes several meters wide), which are characterised by a specific hydrologic functioning. Because of their complexity, they are still underexploited. Moreover, the use of this resource must take into account characteristics specific to the karstic systems, especially their vulnerability to pollution and overexploitation. In regions where water is already scarce and within a context of global change, a better understanding of their functioning has become essential to ensure they are optimally and sustainably exploited and protected. To this end, the regional research units develop different complementary approaches.

Functioning of Complex Aquifers

Study of the functioning of non-saturated zones of karstic systems

The functioning of the non-saturated zone (NSZ) of karstic systems, which can reach up to tens or even hundreds of metres in size, remains poorly known and modelled. Yet, it is now obvious that it plays a major role in transfer dynamics and storage characteristics. The Rustrel (Vaucluse) Low Disturbance Underground Laboratory (LSBB) is located in an artificial gallery (opened for no hydrogeological reasons). The site of the laboratory spans flows within the limestone massif of the Mont de Vaucluse covering a distance of 3,800 metres and reaching depths ranging from 0 and 500 meters.

The site provides direct access to the karst NSZ, hence offering an exceptional research opportunity. Thanks to direct (geological, hydrodynamic, hydrochemical) and indirect (hydro-geophysical) measurements carried out on this site, the EMMAH JRU is developing an operational model of the karstic aquifer NSZ. Eventually, it will be possible to precisely assess the impact of the NSZ on the global functioning of these aquifer systems. The experimental site of the LSBB, located in the supply basin of Fontaine de Vaucluse, will serve as a reference site for the development of this model, which will then be validated and refined through its application to other systems.

In addition to studying the karstic aquifer as such, the work carried out in the Fontaine de Vaucluse catchment basin includes the whole upstream area: vegetation, land use, definition and mapping of drainage units. The impact of the karstic system on the environment downstream from the spring is also studied under different aspects (flood warning, biodiversity and green tourism).

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**Multi-uses management of the Lez river catchment basin karstic aquifer**

The “karst and heterogeneous environments” research group within the HSM JRU focuses on underground and surface transfers in this type of environment. Within the framework of its research activities combining hydrogeological, hydrological and hydraulic characterisation and modelling, the laboratory participates to a broad-reaching research project. The project is entitled “Multi-Uses Management of Mediterranean Karstic Aquifers” and is being coordinated by BRGM for Montpellier Agglomeration, in collaboration with the G-EAU and TETIS JRUs, the Biotope company and the European Centre for Research and Advanced Training in Scientific Computation. This 3-year project started in June 2009 (mainly funded by Montpellier Agglomeration with co-funding from the Rhône - Méditerranée - Corse Water Agency, the Hérault General Council, the BRGM).

It mainly concerns the Lez catchment basin (France) as well as the associated karstic aquifer, and deals with resource management and flood hazard mitigation issues. The project serves the following main objectives:

- To get a better knowledge of the hydrogeological underground environment, through a better understanding of underground flows and geology of this type of peri-Mediterranean hydrosystem;
- To assess the quantitative and qualitative vulnerability of the aquifer;
- To reassess the water resource that can be exploited within the aquifer and characterise the impacts of global changes using different models;
- To characterise the role of the karstic aquifer in the hydrological regime of the Lez river in order to better evaluate flood hazard as well as the chemical and geological quality of the hydrological environment;
- To take stock of the situation of the underground biodiversity of the Lez aquifer;
- To study the effects of actively managing the karstic aquifer on flood mitigation using coupled hydrological and hydrogeological models.

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**Geodesy to study water resources in a karstic environment**

For several years now, the “Risk” team of the GM JRU has been conducting original research works on the monitoring and localisation of fresh water resources in karstic zones.

In 2011, within the framework of the OREME Observatory, and in partnership with the National Institute for Universe Sciences, the H+ Observatory, the Maison de l’Eau water science centre and the companies imaGeau (Montpellier), MicroG and GWR (USA), GM established a geodesic observatory on the Larzac plateau. The aim of the observatory is to bring new knowledge based on very high tech original observations over long periods of time.

The observatory includes the first new generation supraconductor gravimeter (iGrav) developed by GWR, as well as one of the 50 absolute gravimeters existing in the world (MicroG). Gravimetry consists in making surface ground mass measurements in order to determine water bodies and their temporal variations without drilling any bore hole. This type of measurement has become so successful that it is now being exported to other karsts such as the Vaucluse plateau.

The Larzac observatory also welcomes French and foreign researchers who wish to collaborate on research works in progress, both in geophysics and in hydrogeology. The observatory is a training site enabling students from UM2 and all over France to work on current topics using high tech tools. The data collected will make it possible to better understand and model karstic aquifers so that quantitative information can be provided to help with the exploitation/protection of the Larzac water resources and of karstic zones in general.

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Since 2004, the BRGM EAU/NRE research unit has been working on the issue of karstic flash floods. This work comprises several projects with the aim of providing long-term assessments. A first research project for the city of Nîmes (France) targeted the functioning of the Fontaine de Nîmes karstic system in flood conditions. It has evidenced the flood buffering role when the aquifer is undersaturated. It has also showed the karstic system’s major contribution to the genesis of devastating floods in Nîmes, especially that of underground waters during a flood peak.

A tight monitoring of the underground waters has thus been proposed to the Nîmes authorities. Furthermore, a warning tool was designed, based on an abacus. This tool is able to forecast flood magnitudes. It takes into account the saturation condition of the karst and the real-time weather forecasts. This type of approach has been replicated in other karstic catchment basins following a request from the Central Department of Hydrometeorology and Flood Forecast Support (SCHAPI). The tools developed for the forecasters are currently being tested by the Flood Forecasting Departments.

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Real-time flood forecasting is a complex issue with vital economic and societal implications. The complexity stems from the coupling between atmospheric, hydrological and hydrogeological models.

The EMA LGEI research unit studies and implements the methods it develops on the catchment basins of the Gardon river in Remoulins and its upstream outfalls in France. The site is known for the devastating “gardonnades” (river Gardon flash floods). The models developed will then be validated on the Cèze and Ardèche rivers, also known for their flash floods, and on the Somme river, known for its table floods.

The use of neuronal-type networks offers a new alternative: it consists in taking advantage of experimental data recorded during the elaboration of models, obtained through artificial learning. The first results show that floods of the Gardon river at Anduze can be anticipated without any rainfall forecast even for short time horizons (2 to 3 hours), thus enabling the local authorities to take the first decisions rapidly. The purpose of this method is to publish a “vigicrues” flood vigilance map on the internet. These research efforts are being carried out within the framework of the FLASH project (Flood forecasting with machine Learning, data Assimilation and Semi-physical modelling), in collaboration with national partners (SCHAPI: Central Department of Hydrometeorology and Flood Forecast Support, School of Industrial Chemistry and Physics of the City of Paris, “Mountain environments, dynamics and territories” JRU), and with the financial support of the French National Research Agency.

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* www.vigicrues.gouv.fr

Methodology for the evaluation of rainfall runoff hazards

Rainfall runoff is a phenomenon poorly taken into account and rarely dealt with as a full scale risk. It is often confused or associated with floods. Yet, it may cause severe damage. The complexity of the phenomenon stems from its sudden and highly localised occurrence. It usually affects small urban and rural catchment basins. Its characterisation is very difficult since the phenomenon is influenced by numerous physical parameters but mainly because it is aggravated by human activities.

The methodologies currently implemented to study runoff are mainly based on quantitative studies and/or modelling. The work carried out by the EMA LGEI research unit uses a hydro-geomorphological approach to characterise and spatialise the phenomenon. A rainfall diagnosis method has been developed and applied to a rural community.

The qualitative approach used makes it possible to take stock of the general situation. All information and data can be integrated into a qualitative map. Using this approach, a global spatial analysis was performed. Associated with permeability measurements, the trends observed by the qualitative analysis have been confirmed.

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Satellite measurement of river flow rates

Satellites are very useful tools for quantifying global biophysical variables and monitoring their time-space dynamics. They contribute to water cycle knowledge by measuring atmospheric humidity, rainfall, ground humidity, evapotranspiration and the topography of hydrographic networks.

Measuring river flow rates is a major challenge for future satellite missions. The TETIS JRU carries out research work in this field together with the National Space Study Centre (CNES), the French Aerospace Lab (ONERA) and industrial stakeholders in the space industry (European Aeronautic Defence and Space Company; Thales Alenia Space; Collection, Localisation, Satellites, Noveltis). The work is devoted to measurement technologies for river surface variables. These variables are then integrated in order to derive river hydraulic parameters and calculate flow rates.

Three families of spatial techniques are being developed. Radar altimetry (Lidar) makes it possible to measure river levels; TETIS develops qualification methods for measuring river levels and quantifying their uncertainty. As part of the Surface Water and Ocean Topography mission (NASA-CNES), spatial radar interferometry is used to measure slopes; TETIS studies the roughness of water surface and its influence on radar retrodiffusion. TETIS is also involved in airborne campaigns to validate radar devices, processing chains and models. Finally, time interferometry makes it possible to measure surface velocities; TETIS takes part in exploratory airborne campaigns and explores the modelling of this technique on rivers.

In order to assess the flow rate of rivers by means of satellite measurements without in situ measurements, TETIS develops hydraulic equation inversion methods that make it possible to determine river bed parameters (level, slope, roughness of bed, velocity profile), using surface variables only. These methods constitute a coherent framework for specifying future space missions and improving knowledge of the world river flow rates within the next twenty years.

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▼ Rio Madeira in Brazil.
Utilisation of very high resolution satellite images: study of the geomorphological origin of water routes in Mediterranean catchment basins.

The intensity and variability of precipitations together with the complexity of hydrological processes in Mediterranean catchment basins somewhat limit predictability of extreme phenomena. A better understanding of the processes involved in the hydrological responses of catchment basins, which are responsible for the spatio-temporal variability of water routes, could make it possible to improve the modelling of this type of event. This research (LGEI/TETIS research units collaboration) falls within the framework of geomatics applied to hydrology. It entails the use of satellites (especially very high resolution 3D products for the spatial characterisation of basins and their hydrographic networks), to study the geomorphological origins of the spatio-temporal variations of hydrological responses.

First, using spatial data, the “potential” drainage system representing the dry geomorphological network formed by the continuous thalweg lines of the basins is defined. An original algorithm using a terrain digital model structure in a triangular form has been developed specifically for this purpose. It makes it possible to faithfully plot the networks in relation to their real routes and provides information about their geomorphology and that of the basins. The second research area concerns the study of water or “real” drain dynamics. The purpose is to better understand the spatial dynamics of drain water filling over the course of different flood episodes. To this end, a spatialised network of light sensors has been distributed over two experimental basins (< 1 km²) located on the Anduze Gardon. The idea is to monitor the time-space variations of the hydrological dynamics in the water networks.

By comparing and contrasting the geomorphological characteristics and hydrological responses observed, the predominance of sub-surface flows in the basins studied has been confirmed. This has also led to evidence two types of networks with different functioning and has underlined the important influence of the slopes and their changes on the initiative and sustainability of flows within the networks. Finally, it has led to hypotheses about the different functioning of these networks in relation to episodes.

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Mapping of vine evapotranspiration from satellite images

The LISAH JRU has designed a simple vine evapotranspiration mapping method. The study concerned the lower valley of the Peyne river, a tributary of the Hérault river, where vines cover more than 70% of the surface. Twelve ASTER images were acquired between July 2007 and October 2008. These surface temperature images (with a spatial resolution of 90 m), were then converted into daily evapotranspiration maps using water deficit index (WDI) and simplified surface energy balance index (SSEBI) values, which so far had never been used on vines.

These maps were then validated by means of a measurement device installed on seven vine plots deemed to be representative of the soil-landscape variability of the Peyne valley. Evapotranspiration was measured directly using turbulent covariances on two of these plots. By means of regular soil moisture and water table level monitoring, it was also possible to precisely assess the daily evapotranspiration of the seven plots, via the HYDRUS1D hydric transfer model.

The evapotranspiration maps made from satellite images were then successfully validated, the SSEBI index being slightly more precise (0.8 mm/day) than the WDI index (1 mm/day). The evapotranspiration maps thus obtained exhibit a spatial stability over time, similar to that of 1:25 000 scale soil maps.

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The hydric status of vines and its spatial and temporal variations determine the quantitative and qualitative potential of the harvest. This knowledge is essential to trigger the corrective actions needed to optimise the management of grape quality and the water resources used for irrigation. Being able to spatialise changes of the vine’s hydric status over the cultivated areas is also a pre-requisite for diagnosing the current situation of the water resource and possibly forecasting the impacts of climate change in Mediterranean agricultural environments where vine growing is dominant.

The objective of this research effort (collaboration between ITAP, LISAH, Sciences for Oenology research units; INRA “Pech Rouge” experimental station, the French Wine and Vine Institute, Sydney University in Australia and Talca University in Chile), is to propose an estimation model of the hydric status of the vine in time and space. The model can then be scaled according to the vineyard and production area hence providing operational decision-making support for crop management. The project is thus scaled to offer interesting potential for vine growers.

The model uses and creates synergy so that the data available can be configured differently and according to the targeted scale. Thanks to recent technological progress, and to a network of local geo-referenced measurements to monitor the hydric condition of the vine, it is now possible to characterise the heterogeneous aspects of crops (near infrared air information) and soils (measurement of the apparent electrical conductivity of the soil using high space resolution sensors mounted on mobile vehicles).

These networks of communicating sensors (located in the soil and in the crops), make it possible to collect real-time continuous information (plant and soil monitoring systems). It is already possible to monitor variables and hence obtain indirect and local assessments of plant hydric conditions.

Based on a reference measurement, the spatial extrapolation approach has been validated at the scale of the plot and of the vineyard. It is currently being transferred to an industrial partner (Fruition Sciences) and validated on a larger scale (cooperative cellar).

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**Mapping of vineyards evapotranspiration level in the Peyne Valley (France) and localisation of the seven validation plots.**
Water quality preservation and restoration
Preserving the quality of water resources raises major environmental, sanitary and economic issues for our societies. Aquatic ecosystems host a broad variety of animal and vegetal species whose conditions and dynamics are sensitive to the chemical, biological and physical composition of water. Moreover, water is a vital resource for humans and an essential resource for the development of their societies. Yet, human activities can also be a threat to water quality, because of the substances they release in the environment. The degradation of the physico-chemical and biological qualities of water can induce pathological risks for human beings. This degradation in turn compromises the sustainability of human activities and the environmental functions of the water resource. The impact of agriculture on water resources is particularly illustrative of the challenges science has to take up in order to preserve water quality. Water is increasingly needed for agriculture, industrial processes and energy production. But at the same time, agricultural inputs such as fertilisers and pesticides and industrial effluents are as many sources of water contamination. In an attempt to overcome the challenges of production within a context of water scarcity, agriculture looks for new practices, such as the use of non conventional water (such as treated waste water). Yet, there will be no sustainable agricultural development without a control of the release of contaminating substances and of their mobility in the environment. In that respect, the use of non conventional water may lead to potential contamination of surface and underground water, due to the presence of toxic and pathogenic compounds in waste water.

Many of these issues are being tackled by the regional scientific community: the development of innovative processes for waste water treatment (industrial, domestic, urban); the understanding and forecasting of contaminants concentrations and mobility in hydro systems; the design of landscape development and management approaches to limit the scattering of contaminants in the environment; the development decision-support tools for risk evaluation and water use optimisation. The research efforts concentrate not only on usual contaminants such as metals, fertilisers (nitrogen, phosphorus) and pesticides, but also on emerging contaminants such as drug substances, viruses and bacteria.

One way to reduce environmental pollution is to develop and implement efficient treatment processes of agricultural and industrial effluents. Conventional treatments have mainly been guided by output water quality. The current scientific challenge is to design new processes that meet environmental requirements broader than the sole quality of the effluents processed, integrating energy constraints (development of low-energy processes, or even bioenergy-producing processes). An array of biological, physico-chemical and membrane-based processes are being explored.

The evolution of the contaminants in the environment can only be understood by means of analytical research works that examine the processes involved, be they biological, physical or chemical, and the interactions among processes. In particular, the specific properties of each environment (geology, soils, landscape structures, rural and urban developments, etc.) have to be taken into account. The evolution of contaminants with regard to micro-organisms activity, degradation or modification of chemical compounds, is also an issue. The effect of contrasted climatic and hydrological conditions on the mobilisation and transport of contaminants is a research topic of utmost importance, especially in Mediterranean and tropical contexts.

Finally, water quality preservation necessitates the design of generic decision-support tools, useable in the long term and over large areas, to evaluate, monitor and optimise the effects of human activities on water quality. Associated scientific issues concern time and space integration of the processes involved in contaminants evolution. In particular, digital modelling of contaminants evolution, life cycle assessment and the development of indicators of pollution stresses are areas of major interest.

Jérôme Molénet, Olivier Grünberger & Marc Voltz (UMR LISAH)
Water quality preservation and restoration

Membrane materials and processes for water treatment intensification

The European Membrane Institute Joint Research Unit – UMR IEM (CNRS, ENSCM, UM2), founded in 1998, is a world-renowned laboratory specialised in membrane materials and processes. Its research objectives are based on a multidisciplinary, multi-scale approach:

- Elaboration and characterisation of new membrane materials;
- Implementation of such materials into membrane-based processes used in particular for effluent treatment, gas separation, and biotechnologies related to food and health sciences.

IEM comprises three research departments:

- Design of membrane materials and multifunctional systems;
- Interfaces and physico-chemistry of polymers;
- Membrane-based process engineering.

Within a context of increasing water demand compounded by the scarcity and degradation of the resource, IEM develops multifunctional and innovative membrane materials and processes to intensify water treatment. IEM works with a number of industrial and academic partners through national and international collaborative research programmes.

The following application fields are specifically targeted:

- Water treatment to reach the required water quality (drinking water, process water, etc.);
- Waste water treatment for environmental preservation and/or reuse of treated water (irrigation, cooling water, wash water, etc.);
- Sea water desalination.

Both physical and biological methods are explored to treat water. Physical approaches include:

- Treatment of organic compounds:
  - Coupled processes for the treatment of phytosanitary products, endocrine disruptors, drugs and colouring agents (photocatalysis, enzymatic catalysis, adsorption and membrane processes);
  - Separation by pervaporation;
  - Treatment of the polycyclic aromatic hydrocarbons, using ozonation and membrane processes.

- Treatment of mineral pollutions:
  - Selective electro-extraction of metal cations in diluted solutions;
  - Boron extraction through nanofiltration;
  - Membrane distillation and reverse osmosis for sea water desalination;
  - Extraction and concentration of heavy metals with hollow fibre membrane contactors.

Coupling of membrane separation and biological pathways is also developed in the lab:

- Membrane bioreactor for domestic effluents;
- Treatment of effluents containing phenolic compounds using a membrane enzymatic reactor;
- Treatment of urban residual water coupled with energy production using a membrane reactor.

Moreover, IEM develops innovative materials with specific functionalities:

- Super-hydrophobic membrane for the treatment of water (membrane distillation);
- New membrane synthesised by self-assembled copolymer blocks;
- Copolymer synthesis for the sorption/complexification of metals in the treatment of industrial waste water and the recovery of metals.

Main teams

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Water resources: preservation and management

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The riparian corridors, associating human activities (agriculture, urban development, transport infrastructures, etc.) and natural or semi-natural plant formations (prairies, riparian forests), are factors of control of the ecological and physical conditions of rivers. Hence, they constitute key elements to comply with the European Water Framework Directive (WFD). The restoration of riparian corridors involves various stakeholders at the local level (structures in charge of the management of catchment basins), district level (Water Agencies) and national level (State).

To facilitate the multi-level and multi-stakeholder decision making process, it is necessary to develop tools to assess the anthropogenic impacts on aquatic environments. The Rhône-Méditerranée-Corse water agency has commissioned TETIS to design methods to characterise the anthropogenic pressures along rivers and to spatially model the relations between these pressures and the ecological status of aquatic environments.

TETIS has developed an innovative methodology based on “object-oriented” classification, using satellite or airborne images with a very high spatial resolution, associated with exogenous data. This gives rise to land-use maps of riparian corridors, with the required precision about the nature and localisation of the objects (riparian vegetation, buildings, agricultural plots and associated developments, road infrastructures…). The land-use maps are then synthesised as spatial indicators of environmental pressure.

The relations between pressure indicators and water condition indicators (biological or physico-chemical indicators) are then modelled within the framework of the DPSIR conceptual diagram (Driving force, Pressures, State, Impacts, Responses). This modelling approach is original in the way it takes into consideration the imbrications between functional levels (the station: local level and the catchment basin: global level), and the inherent upstream/downstream dependences in rivers.

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Industry effluents have to be treated before their release in the environment (factories near Alexandria in Egypt).
Environmental assessment, modelling and technologies to serve water quality

The Information – Technology – Environmental Analysis – Agricultural Processes Joint Research Unit – UMR ITAP (IRSTEA, Montpellier SupAgro) develops the scientific and technical bases to design equipment for a more sustainable agriculture and environment-related services. ITAP’s three main areas of research are:

- Information and associated systems: on the one hand, ITAP designs sensors based on optical measurements (vision, spectrometry) for the characterisation of agrosystems and environmental processes. On the other hand, ITAP develops new indicators derived from environmental data (climatic, expert, plot-related, etc.), integrated in decision-support tools, in order to assess the status of agro-ecological systems.
- Technologies: development of ecotechnologies for sustainable agricultural production. New design methods that integrate environmental constraints are studied: eco-assessment, eco-design, built-in design. ITAP specifically works on equipment for the protection and maintenance of crops that minimises the sanitary and environmental impacts of pesticide application techniques. It facilitates the regional platform “ecotechnologies for agro-bioprocesses”, and is a reference centre for agricultural spraying.
- Environmental assessment: ITAP develops and implements environmental and social impacts assessment tools, based on life cycle analysis (LCA) and seeks to optimise the performance of the processes studies. It facilitates the ELSA cluster network”.

Here are some examples of ITAP research works in relation to water:

- FISPRO software: design and optimisation of fuzzy inference systems (IRSTEA – INRA free software);
- Implementation of control facilities of new sprayers and associated procedures;
- Digital modelling of phytosanitary deposits;
- Atomisation of agricultural sprays: influence of certain properties of the liquid;
- Influence of phytosanitary spraying quality on the transfer of pesticides into the environment;
- Phytosanitary products drift in vineyards: real scale tests in controlled environment;
- DRIFTX model of the atmospheric transfer of pesticides during the applications of phytosanitary products in vineyards;

* www.ecotech-lr.org
** Pôle Environmental Lifecycle and Sustainability Assessment : www.elsa-lca.org

* Mediterranean rivers are submitted to strong flow rates seasonal variations, affecting water quality (the Hérault River during summer).
Integration of ecological stakes in the management of intermittent Mediterranean rivers

The MIRAGE project (Mediterranean Intermittent River manAGEment), involving the HSM JRU, associates fourteen European research institutes, two basin management entities and a Moroccan university. The objective of the project is to study the applicability of specific management measures of flash floods and severe low water levels in Mediterranean intermittent rivers, taking into account ecological stakes. It contributes to the enforcement of the European Framework Directive on Water and Aquatic Environments around the Mediterranean Sea. It will also give rise to improved management and development schemes for catchments of intermittent Mediterranean rivers.

Indeed, intermittent rivers of Mediterranean catchments are characterised by a long period of accumulation of pollutants during the dry period and their fast transfer towards the downstream coastal area during flash floods. The combination of irregular flow regime and sudden mobilisation of pollutant masses creates major difficulties for the managers: water resource availability, flood control, water quality and ground contamination. When applied to Mediterranean catchments, the management solutions developed in the context of non-intermittent rivers do not yield the expected results, due to the non-linearity of responses of intermittent rivers and to the absence of reference situations in this type of environment.

The MIRAGE project addresses the following issues: definition of indices specific to the hydrology and ecology of these rivers; development of solutions to control the dynamics of contaminants (organic matter, nutrients and priority substances) in water and sediments; control of the effects of floods on the remobilisation of pollutants. These actions are carried out on five study sites and integrated in two pilot catchments submitted to a broad range of anthropogenic pressures.

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Transformation of polluting elements

The Environmental Biotechnology Laboratory Internal Research Unit – UPR LBE (INRA), located in Narbonne, is attached to the INRA centre of Montpellier from an administrative point of view and to the INRA departments “environment and agronomy” and “microbiology and food chain” from the scientific point of view. It focuses on the concept of “environmental biorefinery”.

For more than 25 years now, LBE research efforts have been targeting the treatment and/or valorisation of wastes from human activities, be they liquid effluents (especially from agro-food), solid residues (agricultural residues, domestic waste and sludge from waste water treatment plants), or biomass such as micro- or macro-algae. The pollutants transformation processes are carried out by microbial communities, whose complexity stems from their composition, diversity and functional dynamics. The characteristics of these communities – combined with the fact that they can only operate in an “open” environment – have led the laboratory to work on the operating conditions of the bioprocess, with the aim to orientate the microbial reactions of transformation. These developments also take into account health innocuousness constraints (i.e., linked to the presence of pharmaceutical, detergent and/or pathogenic residues).

The transformation processes of the pollutants are studied at different scales:
- Sequences: through the characterisation of kinetics, key physiological systems and microbial population dynamics;
- Processes: through the development of innovative processes, the optimisation of hydrodynamics and bioreactors operations, the implementation of physico-chemical co-treatment techniques.

LBE research efforts have taken these two scales into account, within the context of sustainable paths. The objective is to develop remediation or valorisation devices for effluents and residues, under economic and regulatory constraints, in order to achieve sober, performing, reliable and evolving bioprocesses.

LBE develops six main research axes:
- Research on generic indicators for the characterisation of organic matter and related co-products;
- Knowledge and role of the biotic/abiotic parameters with regard to the services provided;
- Means of action and management of processes and associated ecosystems to act rather than to suffer;
- Control of behaviour and environmental and sanitary impacts of the products issued from the treatment processes;
- Descriptive/explanatory/predictive models in engineering and ecology;
- Engineering and eco-design of industrial chains.

These research efforts concern several domains of competence: microbiology, microbial ecology, biological engineering, process engineering, automatic modelling, life cycle analysis, project and industrial transfer engineering.

Study of chronic water pollution by pesticides: the case of chlordecone in the French Antilles

Chlordexco is an organochlorinated insecticide, used from 1971 to 1993 in the banana tree plantations in the French Antilles. Chlordecone residues are still present in the environment, especially in soils. This situation leads to chronic contamination of rivers, underground tables, (including large drinking water resources) and even of certain crops. Little is known either about the dispersion modalities of this pesticide – which is significantly adsorbed in organic matter-rich soils submitted to tropical rainfall – or about the modalities of plant contamination.

The Chlordexco project, supported by the National Chlordecone Plan and the “Contaminants, Ecosystem, Health” programme of ANR, implies the research units HortSys and Systèmes Bananiens of CIRAD, the LISAH JRU (INRA, IRD, Montpellier SupAgro), the INRA centre of Guadeloupe, the IRD centre of Martinique and the Agrosphere Institute in Germany. It aims at studying the contamination of water bodies through:
- The identification of the determinants of the molecule release within the soil profile and of its transfer to underground tables: the characteristics of chlordecone adsorption/desorption mechanisms are examined taking into account the type of soil, the quality of the organic matter and the mineral composition. A forecasting model of chlordecone migration is elaborated depending on soils hydrodynamic properties and climatic events.
- The identification of sources and dynamics of river contamination at the catchment scale: several measurement stations have been installed in Guadeloupe to characterise the hydrological behaviour of an elementary basin (20 ha) and of a resource basin (400 ha). Environmental contamination is analysed in soils and water of tables and rivers. The transfer pathways and the dynamics of the pollutants are being modelled.

These research works will allow identifying the main zones that contribute to the pollution and to the evolution of the polluting pressure over time at different scales. They will contribute to diagnose the importance and the short and long terms evolution of underground and surface water contamination. They will help to better understand the chemical stresses suffered by aquatic organisms. Finally, they will end up with recommendations for a better environmental management.

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LBE is one of the world leading laboratories in the field of anaerobic digestion. It promotes excellence in research, thematic plurality, multidisciplinary approaches, innovation and technology transfer (6 patents, 11 licence contracts, Pollutec Innovation Awards in 2007, 2009, 2010). Its facilities cover more than 4,700 m², including a 1,900 m² experimental hall, high performance scientific and analytical equipment, with more than 50 digesters (from 1 litre to several cubic meters), running on a 24/7 basis.

Analysis of minerals in water

The Water, Soils and Plants Analyses Internal Service Unit – US Analyses (CIRAD) is an analyses laboratory with a staff of 19, based in Montpellier. It is specialised in the analysis of mineral constituents, including metal trace elements, in plants, water, soils and other media related to agriculture (harvest residues), environment (waste water treatment plant sludge), or the food industry (table oil). It plays a cross-disciplinary role by serving other research units of CIRAD and other public institutes (INRA, CNRS, IRD, etc.).

The lab is accredited by the Ministry of Agriculture to import and analyse soils from non-European countries. It is well-equipped with analysis devices such as inductive coupling plasma (ICP), inductive coupling plasma mass spectrometry (ICP-MS), continuous flow colorimeters, automatic granulometers, pH-meter automat controller, C, H and N elementary analysers, atomic absorption spectrometer with electrothermal atomisation, polarographic chain.

The lab is also accredited to train students and researchers in analytical techniques. It carries out methodological studies on laboratory and field experiments. It is also destined to train, control and evaluate other analyses laboratories in terms of metrology and quality control. Since 2000, the lab is certified by the French Association for the Improvement and Management of Quality according to the ISO-9001-2008 standards for four types of services (analysis, training, expertise and methodological developments). With regard to water, the lab analyses elements present in natural water (rivers, lakes, underground water tables), or in waste water, including mineral pollutants such as heavy metals.
Monitoring sea water intrusion into coastal aquifers through hydrogeophysics: the Campos Observatory in Majorque (Balearic Islands)

The experimental and observation site of Campos (12,000 m²) is dedicated to the study of sea water intrusion in coastal aquifers. It is located within a highly permeable carbonated reef terrain (Miocene) exhibiting some karstic cavities a few meters in size. In this part of the island, intensive farming and irrigation cause the overexploitation of the coastal underground table, leading to sea water intrusion (up to 15 km inside the island), and the progressive pollution of underground water by chlorides. The experimental site comprises a network of 14 deep drillings (100 m on average, plus one 250 m deep), six of which have been bore drilled.

This site has been developed with the support of the Study and Planning Service of the Water Resource Department (Balearic Ministry of Environment), within the framework of the European project ALIANCE (5th European Union Framework Programme, 2002-2005) coordinated by the Tectonophysics Laboratory of Montpellier, now part of the GM joint research unit.

Currently, the project is monitored by the “transfers in porous environment” team of GM, in the framework of the OREME observatory (see page 13).

The main scientific objectives are:

- On site characterisation of the heterogeneous geological medium, by means of drilling measurement campaigns: geological structures (wall imagery), petrophysical characterisation on cores and in situ (electrical, acoustic, natural radioactivity), flow characterisation through hydrogeophysical methods (flowrate by spontaneous potential, hydrodispersive behaviour).
- The continuous drilling-based monitoring of the aquifer using a specific instrumentation designed within the laboratory: i) in geophysics (igeo-SER), for daily measurement of parameters such as electrical resistivity or electrokinetic potential, and ii) in hydrodynamics (Hydreka piezometers or Schlumberger probes), for measurement of pressure and temperature fields and ionic charge of in situ fluids (using a WestBay multi-packers tubing).

The main goal is to study the response of the reservoir to external stresses, be they anthropogenic, natural or induced by controlled experiments. Recently, a partnership between GM and the imaGeau (Montpellier) and Schlumberger-Westbay (Canada) companies has allowed the implementation of systematic observation routines of underground fluids.

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Sources of chemical contamination of water have increased in amount and nature throughout the last century. They can be organic or inorganic, and have a natural or anthropogenic origin. The purpose of the research works carried out by the HSM JRU is to get a better picture of the mechanisms involved in the evolution of these chemical contaminants (metals, metalloids, organometallic compounds, endocrine disruptors, medical drug residues, etc.) in the environment, especially in the water cycle.

Besides the physico-chemical characteristics of the environment, micro-organisms activity plays a key role in the dynamics of these contaminants, by conditioning their chemical form and thus their mobility. Owing to their adaptation capabilities, micro-organisms have developed metabolic or detoxification mechanisms enabling them to interact with chemical contaminants, including xenobiotics. Microbial activity can lead to the biodegradation of organic forms, to the modification of chemical forms, or to the immobilisation of the compounds through precipitation or complexation.

Given the complexity of influencing factors, it is essential to control the processes of contaminant transfer into the environment. This is perfectly illustrated by the research works of HSM on acid mine drainages. These research works have made it possible to partly decipher the biogeochemical mechanisms involved in the dynamics of metallic and metalloid elements in the hydrosphere downstream from the former mine of Carnoulès (Gard), which forms part of the OREME Observatory (see page 13). Micro-organisms are both actors of the generation of acid drainages from mine wastes, by controlling the sulphide oxidation reactions, and actors of the natural attenuation of water pollution, by promoting iron and arsenic oxidation, leading to their immobilisation in the sediments.

This approach has also been developed to study the transfers and ecotoxicity of the metallic and organometallic pollutants from port sediments, during the ECODREDGE-MED project (funded by FUI). It has also been applied in the study of the evolution of drug substances in the coastal environment during the PEPSEA project (funded by ANR).

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A project on the evaluation of the characteristics of underground water tables in zones contaminated by arsenic in Cambodia and Vietnam, in order to develop a household-scale water purification system (2009-2010, funded by the Agence Universitaire de la Francophonie) has been coordinated by the Cambodia Technological Institute (Pnom-Penh) and operated jointly with the Hochiminh Technological University (Vietman) and the CIRAD Analysis lab. The objective of the project was to design a simple, low-cost and efficient device to lower the arsenic content of water taken from the underground water table of the Mekong River in Cambodia and in Vietnam, used as drinking water by the village populations.

The high concentration of this element in water (from 40 to 1,200 µg/l whereas the maximum concentration recommended by WHO for human consumption is around 10 µg/l) is partly of anthropogenic origin (pesticides) but essentially natural, through simple dissolution from arseniferous pyrites present in the upstream portion of this large Asian river. In these regions, the recently evidenced arsenic toxicity causes skin necrosis (arsenosis) which can be lethal.

The device designed is a simple sand bio-filter, made from ordinary materials. It comprises an airing system in the shape of a watering syringe, a nail bed to enrich the iron content and foster the ferric hydroxide formation that traps arsenic, a sand filter with increasing granulometry and a final polishing device made of rice chaff. This device is easy to use, to maintain and efficient at household or small village scale. For this study, the CIRAD Analysis lab provided an analytical support for the characterisation of water sampled in different sites in the two countries and for the validation of the efficiency of the device, leading to arsenic concentrations below 10 µg/l post-treatment.

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CreativERU project: intensive treatment and valorisation of urban residual waters

The CreativERU project (collaboration between the research units IEM, LBE, the Laboratory of Engineering of Biological Systems and Processes of INSA Toulouse, Veolia Water Research and Innovation) is funded by the ANR “Ecotech” programme, open to French-Chinese collaboration. It concerns the development of advanced water treatment technologies, more specifically the treatment of urban effluents. The rather innovative aim is to reach very low carbon and water impacts.

This project should remove the last scientific locks and validate at the industrial pilot scale a new intensive path for urban waste water treatment. This treatment enables producing very high quality treated water suitable for direct reuse (as it is disinfected), while reducing the size of the facilities and the operational costs, or even the equipment costs.

The aim of the project is to define a new treatment concept, with the following differences from conventional systems:

- Production of quality treated water using a porous membrane filtration technology, enabling the resource to be reused directly;
- Strong reduction of the oxygen needs (hence of energy inputs), through the physical extraction of the organic fraction, that is further concentrated for easier fermentation;
- Optimisation of a significant biogas production;
- Optimisation of nutrients treatment to facilitate their elimination and/or recovery;
- Demonstration of the possibility to treat urban waste water to produce fresh water of a defined quality, with a positive energy balance and a minimal environmental impact within a context of sustainable development.

Such a technology would constitute a real breakthrough compared to existing intensive systems only taking into account the requirements for treated water quality, without consideration for the carbon release (linked to energy consumption) and the advantage of saving water.

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Water resources: preservation and management

Regardless of its use – agricultural, household or sanitation – the quality of water or the efficiency of its use and of its treatment is always a matter of compromise between, on the one hand, the use of the water itself and, on the other hand, the consumption of material and energy to save or treat the water. Conventionally, the efficiency of a waste water treatment plant used to be measured only through the final quality of water back to the environment. Yet, such a treatment generates other environmental impacts during the construction, operation, running and decommissioning of the whole sanitation system. Thus, the reduction of local impacts such as eutrophication of aquatic environments or ecotoxicity in fresh water bodies, are impaired by regional or global impacts linked to the infrastructure and operation of the waste water treatment plant. The environmental LCA is the only assessment method able to quantify such impacts over the whole life cycle, from the extraction of the raw materials used to the end of life of the systems studied. Associated with local approaches such as environmental impact assessment studies which take into account the specificities of the site, LCA makes it possible to prevent as much pollution transfers as possible.

The ELSA* cluster, based in Montpellier, comprising amongst other ITAP, LBE and LGEI research units, works in close collaboration with G-EAU on these environmental assessment issues related to water management and use. Since 2010, a project funded by the National Bureau for Water and Aquatic Environments (Office national de l’Eau et des Milieux aquatiques), aims at assessing the environmental performance of the sanitation system of small and medium size local authorities (sanitation networks and waste water treatment plants). Other research efforts related to water uses are in progress within the ELSA cluster: territorial LCA applied to the management of the Thau Lagoon, to an irrigated area, to water uses of a large city, to the production of micro- and macro-algae (INRA-LBE and Montpellier SupAgro). The objective of all these works and associated research issues is to better take into account water and its treatment in the LCA, both as a limited resource and as an ecological medium.

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* Environmental Lifecycle & Sustainability Assessment (IRSTEA, CIRAD, EMA, Montpellier SupAgro, INRA): www.elsa-lca.org
Treatment of industrial effluents for the reuse of water: case of the ceramic industry

Water is fast becoming a concern and a major stake for the coming decades, due to an increasing consumption in all sectors of activity, compounded by the unbalanced renewal of the resource. This situation is especially critical in Mediterranean countries. Assuming they can be valorised by means of an appropriate treatment, effluents become a resource potentially and economically interesting for industrialists. In this context, the utilisation of membrane processes for the treatment of effluents proves to be a solution worthy of attention.

The ceramic industry in Spain is the first in Europe and the second in the world. It is concentrated in a small territory in the province of Castellón, around the city of Castellón de la Plana. The main bottlenecks for the reuse of the effluents from this industry stem, on the one hand, from a high content in calcium and sulphate ions and, on the other hand, from the presence of boron salts which are contaminants unfit for human consumption and for the cultivation of citrus fruits.

The Nanoboron project aims at trapping the boron present in the effluent by membrane separation. It is a collaboration between IEM, the Instituto de Tecnologia Ceramica de Castillon de la Plana [IMECA], Gardenia Quimicas S.A. and Estudio Ceramico S.L. The project was implemented in three steps:

1. Identification of the processes applicable and feasibility at the laboratory scale,
2. Modelling and design of a demonstration pilot system, and
3. In-situ tests and adaptation to the operating conditions with an economic balance.

The laboratory feasibility step (IEM) has led to couple a microfiltration and a nanofiltration process. A demonstration pilot system has then been designed. The in-situ tests and the techno-economic study carried out by IMECA have validated the approach.

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PETZECO project: treatment of petrochemical aqueous effluents through ozone-zeolithe combination

Water and sediment pollution by polycyclic hydrocarbons is unquestionable and induces real environmental and health threats. This situation has led the European Commission to classify these substances as priority issues. The conventional operations of chemical oxidation or adsorption on active carbon show limits linked to cost and implementation. Advanced oxidation processes are suited to the degradation of the bio-refractory or toxic compounds, owing to the use of hydroxyl radicals. The aim of the research efforts made within the framework of the PETZECO project (collaboration between IEM, the Montpellier Charles Gerhardt Institute, the Chemical Engineering Laboratory of INSA Toulouse and Total) is to design a leading technique for the treatment of difficult industrial waste water.

The main idea of this project is to use ozone combined with innovative zeolithic materials, in order to associate the decomposition capacity of ozone into hydroxyl radicals with the adsorption properties of zeolithe. This combination triggers a synergy and should accelerate the degradation speeds. The utilisation of a mineral porous solid should guarantee a good resistance to oxidation and maintain long term adsorbing and catalytic properties.

The development of this new zeolithe-type solid mesoporous adsorbant/catalyst is one of the major challenges of this project, since very few studies have been done in this domain. The implementation of this catalysts/ozone combination in an efficient, low cost process is another challenge for this project. The chemical and mechanistic aspects will be studied in depth to target the most interesting functionalities of the solid during the zeolithe synthesis. The parameters used to size the oxidation process in different configurations are studied in depth (from fluidised bed to the membrane-based separation of the catalyst). The ultimate goal of the project is to use monolithic materials that contain the new catalyst on real petrochemical effluents.

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The BIORARE project: bioelectrosynthesis for residual waste refining

BIORARE is a collaborative project that involves the IRSTEA research units “Hydrosystems and Bioprocesses” and “Environmental Engineering and Biological Treatment of Wastes”, the joint research unit “Chemical Engineering Laboratory” (CNRS, INPT, UPS), the INRA research unit LBE and the company Suez-Environnement. It focuses on the modalities of use of the concept of “microbial electro-synthesis” for the bio-refining of wastes and effluents. This recent discovery allowed the production of high value-added molecules using organic matter and energy present in wastes.

The main idea consists in using the technology of the bio-electro-chemical systems, not to produce electricity as in “bio-energizer”, but to orientate the metabolic reactions of the bioprocess towards the production of molecules of interest, usable in green chemistry. These microbial electro-synthesis systems offer essential advantages:

- Physical separation between a “dirty” compartment that receives the organic matter to be treated and a “clean” compartment in which the synthesis of the molecule of interest takes place;
- Possibility to orientate the metabolic flows and to select the oxidation reactions that occur at the cathode, through voltage regulation.

In order to elaborate a detailed specification for the application of microbial electro-synthesis, the key components will be identified as well as the specifications associated with the elaboration of a subsequent industrial development strategy. First, it will be necessary to strengthen the microbial electro-synthesis scientific and technical bases. The relations between the operating conditions and the molecules effectively synthesised will be validated experimentally at laboratory scale. Multidisciplinary approaches shall be combined in order to better understand and appreciate the technological potential of these systems. In parallel, there will be an environmental assessment of the strategies used to couple these systems to the existing industrial facilities. This work will be carried out on the basis of reference scenarios which will allow the identification of environmentally sensitive components, in order to orientate the technical or industrial choices. Finally, an economic, societal and regulatory analysis shall be undertaken to achieve a better definition of the future industrial development strategies. The intellectual property right measures will be taken whenever necessary.

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Treated waste water for irrigation: towards better risk assessment

The world faces a problem of water scarcity caused by global warming, demographic growth and diversification of water uses. The reuse of treated waste water could be one of the solutions to this problem. It makes it possible to use in priority conventional waters for uses that require high quality, and to prevent the overexploitation and salinisation of coastal aquifers. The treated waste water used for irrigation is therefore not discharged in rivers, in the aquifers or in the sea, and the agriculture benefits from its fertilising potential (nitrogen and phosphates). However, the use of treated waste water for irrigation induces environmental and health risks. It could contain various toxic compounds harmful to the flora, fauna and humans, as well as human enteric pathogens. Its salinity may cause soil degradation. The risks depend on the origin of the water, its treatment, its management, the health condition of the populations, etc.

EMMAH is currently taking part in a European survey about the use of treated waste water with regard to practices, risks qualification and quantification, epidemics linked to water quality, evolution of pollutants and pathogens in the environment, regulations with their advantages and their implementation difficulties. EMMAH has initiated research efforts on the evolution of viruses in the environment, notably with a substitute to the hepatitis A virus (mice Mengovirus). It wishes to extend its work to the Norovirus responsible for most of the viral gastroenteritis, or even to the Rotavirus responsible for the same disorders in children. It looks into the evolution of this virus in the soils, at the surface and in the atmosphere. It will also look into the evolution of certain antibiotic-resistant bacteria detected at the inlet and outlet of waste water treatment plants, as well as into the effects of the salinity of waste water on the structural stability of soils. EMMAH uses various methods and develops models that couple different processes: site visits with reuse of the treated waste water, in-situ and laboratory experiments, analysis of the processes underlying the evolution of the pathogens studied.

The final objective is to gain a better knowledge of the processes associated with the evolution of certain viruses and bacteria in the environment, to integrate this knowledge in mechanistic models and finally to develop decision-support tools for public authorities. Through this project, EMMAH will also be involved in the setting up of new warning sensors.

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Traditional irrigation system in Syria.

F. Molle © IRD
Management of resources and uses: institutions, territories and societies
he scarcity of such a vital resource as water, to supply societies and their livestock, irrigate their crops or produce energy, led these societies to draw up rules for water access and sharing. The study of such initiatives falls within the scope of economics, management and social sciences. Nevertheless, attempting to reverse this natural resource depletion and degradation trend through human and social sciences has long been questioned, and even subjected to controversy.

The harshness of the debate on whether priority should be given to hydrological or social sciences has calmed down as awareness has increased on the growing scarcity of the resource, with the drying up of rivers, streams and wetlands during dry seasons, followed by water-use conflicts, particularly acute in Mediterranean and semi-arid regions.

Indeed, the "water demand management" concept (WDM) implies that saving water is an essential prerequisite to mobilising new or alternative resources, so as to be able to balance management of water resources and associated uses. Implementation of the WDM concept was acclaimed by water managers from the Mediterranean countries during a workshop in Fréjus (France) in 1997. Some authors recommend avoiding water wastage, or saving water within each usage category, by adopting tailored technologies and incentives. Inter-sectoral management of water is also advocated, for example, by transferring water usage rights from one sector to another, depending on the priorities of the competing uses.

Scientists now assess these issues from economic, social and management sciences standpoints, in order to understand, formalise or regulate individual or collective water allocation and consumption behaviours and thus achieve water savings on an adequate scale. This is certainly a break from existing approaches considering, in addition to initiatives necessary for mobilising water resources, those that impact demand at different inter-sectoral scales.

Reflecting a new way of considering water resources management, this change in paradigm is being increasingly adopted by stakeholders in this domain. This approach is now privileged in regulatory texts such as the European Water Framework Directive (WFD, 2000), the first to be so widely based on economic concepts. It imposes a minima incentives to save water through pricing instruments, while recommending concerted management and the introduction of public participation.

The scope and variety of the regional scientific community’s work extends beyond WDM per se. It makes the best use of its many assets to:

- Contribute to drawing up public environmental policies, especially streamlining them with territorial economic development and planning policies. This involves analysis of conditions for the governance of water resources, uses and services in order to meet objectives concerning the quality of water and aquatic environments, that are shared by stakeholders at adapted territorial scales and to come up with renewed terms and conditions for management and consultation.
- Design a wide range of regulatory, economic, institutional or technical instruments that could enhance the implementation and effectiveness of environmental policies at the “water territory” level. Innovations in this domain are notably dependent on the development of modelling and simulation platforms for the study of interactions between biophysical mechanisms and decision-making processes and between the different levels of management and decision.
- Most of the research units are involved in international projects including Mediterranean areas and thus frequently deal with risk management and territorial vulnerability with regard to flood and drought. According to forecasts of the Intergovernmental Panel on Climate Change (IPCC), these extreme events are likely to increase, so it is all the more necessary to enhance the resilience and medium-term adaptability of these areas.

A brief glimpse at the lines of research and projects carried out by the research units that are covered in this chapter clearly highlights two features of the research work:

- The territory, which is the relevant scale for environmental and other public policies implementation, is almost systematically the focal point of the research. Observatories, governance and spatial information management are thus items of growing importance.
- The research is carried out at the interface of several disciplines, either internally within multidisciplinary research units, or through collaborations, giving evidence of the recent astounding development of multidisciplinary works among hydrological, economical, management and social sciences.

With these qualities and the backing of the “Water” competitiveness cluster, the regional scientific community would appear to be in a good position to contribute to meeting the challenges to satisfy the society’s needs while preventing water resource degradation.

Thierry Rieu (UMR G-Eau)
Management of resources and uses: institutions, territories and societies

The sustainable management of water resources: stakeholders and uses

The “Water Management, Stakeholders, Uses” Joint Research Unit – UMR G-EAU (AgroParisTech, IRSTEA, CIHEAM-IAMM, CIRAD, IRD, Montpellier SupAgro) aims at building knowledge and identifying levers for sustainable water resources management. The priority is given to the European and African continents, with a special focus on the Mediterranean basin. Multidisciplinary approaches are being developed, bringing together earth sciences (hydrology, hydraulics), engineering (automation, fluid mechanics), life sciences (agronomy, hydrobiology) and social sciences (economics, sociology, political science). Modelling is a mediator between disciplines, research workers and stakeholders. G-EAU research activities are structured along three lines, plus a cross-sectoral training activity.

The first line of research, “from operational management to the analysis of resource allocation scenarios”, aims to improve management of scarce water resources, mainly through a quantitative biophysical approach, while the qualitative aspects are addressed from a hydro-biological standpoint. G-EAU is interested in water in regions hampered by shortages, should the resource be rapidly-moving (rivers, pipelines), slowly-moving (aquifers) or temporarily stored (dams). The management issues are addressed according to two approaches:

1) regulation of natural or artificial systems for “real-time” operational management;
2) analysis and assessment of the impact of overall changes in the strategic management of man-made basins (larger time scales). The tools and initiatives range from the production of data in the field to physical modelling.

The second line of research, “public policies, management of water-associated services and risks”, deals not only with public action, regulation and multilevel governance, but also with behaviours and vulnerability in risk situations. As regards public action, interest is particularly focused on (i) installations and analysis of institutional dynamics in the implementation of collective actions; (ii) construction and role of observatories and indicators in the water domain; (iii) regulation and sustainability of water utilities and iv) economic and institutional approaches and relations between agriculture and services provided by hydrosystems. Concerning behaviours, the aim is to qualify the demand for water in its different uses so as to assess their sensitivity to different forms of regulation or to analyse the socioeconomic dimensions of vulnerabilities in risk situations (floods, pollution).

Research along line three – “irrigated agriculture” – deals with irrigation practices from equipments to irrigated areas with a focus on farms, through three topics: (i) analysis of the physical processes for the design and sustainability of irrigation equipment; (ii) multicriteria and multiscale evaluation of irrigated systems performances and (iii) support for technical and institutional innovations in irrigated areas. **
Climate change will increase the frequency of extreme climatic events, such as droughts, floods and hurricanes. These climatic anomalies could have disastrous consequences for countries already affected by poor drinking water supply and those depending mainly on local agriculture. Given that agricultural activities represent 60 to 100% of the income of the poorest African households and that these households often have no access to drinking water, Sub-Saharan Africa is one of the regions in the world the most sensitive to climate change. Today, there is consensus about the fact that drought (and desertification) is one of the causes of the civil war in Darfur, by increasing the tensions around the use of arable land and water. It can therefore be suggested that climate may generate conflicts by increasing competition for resources.

The LAMETA JRU analyses the links between climate and conflicts occurrence in Sub-Saharan Africa. This research comes within the framework of emerging studies about the role of natural factors in the emergence of conflicts (published in Nature, for example). Previous research works focused on the link between short-term climatic anomalies and the occurrence of civil wars, using raw data of precipitation and temperature. In other words, only climatic “shocks” were taken into account and no consensus could be found among scientists about a formal link between conflicts and climatic conditions. Using the Palmer* drought index, LAMETA has considered drought as a “stock” (of water and consequently food) rather than as a temporal climatic shock. This index is particularly well-adapted to evaluate the consequences of climatic variations on agricultural activities and considers drought as a cumulative phenomenon. The results obtained in this way show a positive relationship between drought and civil war and, unlike previous studies, are highly statistically significant.

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Droughts and conflicts

PREVENTION AND MANAGEMENT OF WATER-RELATED RISKS

Dried soil in the Tafilalet Valley, Morocco.
PREVENTION AND MANAGEMENT OF WATER-RELATED RISKS

Preventing and combating floods, pollution and marine submersion in Languedoc-Roussillon and Provence-Alpes-Côte d’Azur

HYDROGUARD, a 2009-2012 project approved by the “Risks” competitiveness cluster, aims at developing a reliable, autonomous and automated monitoring system for the follow-up of watercourses and coastlines of the Languedoc-Roussillon and Provence-Alpes-Côte d’Azur regions. More generally, it aims at supporting local authorities in the sustainable management of water bodies and territories. The devices can be fixed on buoys or set up in sensitive areas, or transported in a mobile form to be installed in varying zones at times of alert.

To ensure the profitability of the investment, the devices, equipped with detectors/sensors, onboard communication and computer systems, are not only used upon alerts (floods or storms), but also under normal circumstances to detect pollutions, to monitor the evolution of water bodies and coastlines, or even to measure erosion or any other relevant indicator. This equipment could thereby be used in monitoring strategies, in alert systems (particularly in situations of flood or marine submersion) and in the management of water bodies. This new system is consistent with European and national regulations, as well as with existing standards. In case of alert, this system is an ideal tool for anticipating actions, contributing to decision-making and orienting rescue teams, thanks to the information captured by its detectors/sensors. In normal situations, the system can be used to pass on relevant information to government departments and services, local authorities, private individuals, industrial site managers and service operators. The system’s originality lies in its decentralisation, its proximity, its redundancy and its inter-operability with other existing systems (CEMER, ALADIN…).

This project targets the municipal scale on two pilot sites (the city of Alès and municipalities around Etang de Thau). These areas are representative of issues linked to water bodies management, rapid flood risks, lagoon and marine submersion and dune ridge rupture, with important human and economic factors at stake.

2D/3D visualisation tools will be connected to the system to allow displaying the monitored areas using suitable visualisation flows. Data collected by the sensors will be synthesised in real-time to properly inform end users.

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* HYDROGUARD: Autonomous equipment and technologies for the optimised management of the means of prevention of floods, pollutions and marine submersion in LR and PACA.
of rural systems; (2) Governance and management of resources and territories; (3) Risks and vulnerability of societies and territories. Cross-sectoral themes relate to specific topics (conflicts and access to resources...) and/or environments (forests...) common to the three lines of research. Research on water comes under the second line. Indeed, water and hydrosystem governance represents both a priority focus for public development policies and a strategic challenge with respect to societies’ dynamics, as revealed by the frequent conflicts associated with access to territorial resources and discrimination surrounding this access.

The “Social water management” team focuses on rural societies, studying transformations that affect them in the context of growing pressure on water resources and a changing economic and socio-political environment.

This research specifically focuses on issues about water resource sharing and the decision-making power between the public, private and community stakeholders. It deals with modes of coordination and mediation of stakeholders facing repeated water-use conflicts, thus inducing changes and innovations. This is a contextualised and process-based approach, anchored in the historic nature of the trajectories and situations. It focuses more specifically on the strategies of individual and collective stakeholders who are hampered by the existing institutional frameworks while intervening at different levels to facilitate changes.

The team also works on defining public policy, and thus on the State as a pivotal stakeholder in the transformation of water regimes and the introduction of formal rules and incentive structures. It thus questions the social distribution of the costs and benefits attached to the different public policy options and the ideological and cognitive dimensions of public policies.

The French government requires that policies implemented in the framework of flood management be systematically assessed for their economic relevance. To this end, the TETIS JRU develops a cost-benefit analysis tool, based on the method of avoided damage for contracting authorities. Such a tool produces various spatial indicators to compare the economic effectiveness of different policies implemented to prevent flood. These indicators rely on an estimation of the potential damage linked to different high water scenarios, obtained by crossing random spatial data with information about risk level, land use and usage vulnerability.

The control of uncertainties linked to this tool is an essential point of its performance and usefulness. IRSTEA, a leader in the development of this kind of tools in France, in partnership with AgroParisTech, UM2, and the Plan Rhône partners, has developed a framework for the analysis of uncertainties and consequent sensitivity of economic indicators. This scientific collaboration is designed to facilitate transfer of the knowledge produced towards the operational world, through a methodological guide and a computerised tool for the analysis of costs-benefits, uncertainties and associated sensitivities.

The project also explores purely scientific issues like the crossed influence of the nature and spatial extent of input data on the resolution of output indicators. The results obtained will guide the State or Plan Rhône future strategies on data collection to implement cost-benefit analyses.

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The model for damage assessment during flood events in the Orb Valley (Hérault, France): the blue form is a map of submersion levels in the low Orb Valley (darkest colour = highest water level).

Graphics represent respectively sensitivity indexes of the various input data used in the model (on the left) and uncertainty about total damages caused by the flood, calculated using a cost-benefit analysis–avoided damages model (on the right).

N. Saint-Geours © UMR TETIS
Economics to improve agricultural water management

The “Montpellier Laboratory of Theoretical and Applied Economics” Joint Research Unit – UMR LAMETA (CNRS, INRA, Montpellier SupAgro, UM1) works, among other themes, on “sustainable development and natural resource management” policies. In particular, LAMETA develops economic instruments for the improvement of qualitative and quantitative water management relative to agricultural activities.

LAMETA works in collaboration with several other research units of the regional community: LISAH for hydrological aspects, SYSTEM for agronomic aspects, G-EAU for social aspects and systems modelling. Over the past five years, LAMETA has also strengthened its international cooperation network, especially with various Australian institutions (Ministry of Primary Products of Victoria State, University of Melbourne, University of Western Australia, Australian National University, University of Sydney), which involves researchers and Ph.D. students exchanges in both directions.

LAMETA research on water combines three approaches:

- Theoretical microeconomics and public economics approaches to analyse the efficiency of water management tools and mechanisms proposed in situations where information is lacking between agricultural users and public authorities and when water resources are uncertain. Within the framework of the European NOVIWAM project (Novel Integrated Water Management Systems for Southern Europe), new forms of pricing have been developed which provide incentives for farmers to “book” their required irrigation water volumes in advance, so as to guarantee the availability of the resource.

- Experimental economics approaches, either in the laboratory or in the field with water users, give a better picture of their reactions to the proposed instruments. These “testbed experiments” tools are used to assess the behaviour of economic agents with respect to public intervention. LAMETA has an experimental economics laboratory on the Richter site (LEEM, Montpellier) and a mobile laboratory to facilitate field experiments.

- Integrated modelling approaches, requiring coordination with other disciplines (hydro-geology, agronomy, ecology, etc.), are usually based on in-depth field studies. These models take into account the interdependences between land-use patterns, territorial planning and water management programmes.
Recently, France has been confronted to several drought periods (2003, 2004, 2005, 2006, 2011) recalling the important impact of this phenomenon on agriculture, main water consuming sector and economically the most affected one. In a number of places, prolonged droughts induced structural shortages, with low water levels in reservoirs or water tables used for irrigation. Moreover, most global warming scenarios forecast more frequent drought occurrences. Thus, providing tools to efficiently regulate water demand appears to be of prime importance.

The RISECO project (funded by ANR) proposes to carry out an economic analysis of water shortage issues and related risks in France. It brings together economists from the G-EAU and LAMETA JRUs, IRSTEA, INRA and Montpellier SupAgro. The project is based upon dynamic modelling methods, econometric analysis and experimental economics.

Different economic instruments are analysed and compared in terms of efficiency for the management of water shortages. For example, the project proposes to analyse the role of irrigation and harvest guarantees in the management of drought risk by farmers. It assesses how “water rights” can promote a share of both resource and risk. It evaluates the interest of “water rights” systems, with different water supply guarantee levels, enabling farmers to build up a more or less sure “portfolio of rights”, depending on the way they manage shortage risks. Finally, it proposes an original method of water pricing, based on a varying water price depending on uncertainty about the availability of the resource. These questions have practical field applications, for the management of extractable volumes or for water pricing by regional development companies.

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**ÉTAT DES ARRÊTÉS DE LIMITATION DES USAGES DE L’EAU**

**71 DÉPARTEMENTS SONT CONCERNÉS PAR AU MOINS UN ARRÊTÉ PRÉFECTORAL EN VIGUEUR AU 11 JUILLET 2011 ET LIMITANT CERTAINS USAGES DE L’EAU. 7 DÉPARTEMENTS SONT EN VIGILANCE.**

État des arrêtés de limitation des usages

- **Inclus**
- **Arrêté**
- **Mesures de limitation des usages non effectives mais des mesures ont été planifiées à long terme en cas de nécessité (arrêté-adsres)
- **Niveau 1** - mesures limitées : toutes mesures de limitation des usages inférieures ou égales à 1/4 de l’utilisation communautaire au niveau du bassin versant.
- **Niveau 3** - mesures très fortes : mesures de limitation des usages supérieures ou égales à 3/4 de l’utilisation communautaire au niveau du bassin versant.
- **Nouveaux départements concernés (déclara entre le 9 juillet et le 11 juillet 2011 : aucun)**

*Source des données : préfectures, fonds cartographiques : IGN – BD GDT IAD*
The POPSY project “Field crops production systems, Environment, Public policies” (2009-2013) is funded by ANR and coordinated by the “Public economics” research unit of INRA Versailles-Grignon. It brings together economists and agronomists. The aim of this project is (1) to develop methods for the design of ecologically-performing production systems, using less pesticide, (2) to study the socio-economic conditions for the emergence, the development and the adoption of such systems and (3) to assess the impact of current change setting.

Within this project, LAMETA particularly studies the reasons why territorialised agro-environmental measures for pesticide reduction are left ahead by stakeholders in territories where “water” is a strong stake. It experiments new systems for the allocation of individual or collective agro-environmental contracts, which are more effective and more motivating for farmers (especially the vine growers of Languedoc-Roussillon). LAMETA also participates in a pilot experiment, with the Artois-Picardie Water Agency, of contracts allocation for permanent green cover through auctions.

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Auction advertisement for the creation of herbal covers published in the document of presentation of the “water and agriculture” programme of Agence de l’Eau Artois-Picardie.

Managing spatial information to gain insight into and manage resources, environments and territories

The “Territories, Environment, Remote Sensing and Spatial Information” Joint Research Unit – UMR TETIS (AgroParisTech, CIRAD, IRSTEA) aims to develop spatial information management methods to enhance knowledge and management of environments and territories. TETIS conducts conceptual, methodological and thematic research using an integrated approach to the information chain: acquisition – notably by satellite – of spatial data; the spatio-temporal analysis and modelling of agro-environmental and territorial systems; design and management of information systems; processes for the appropriation and use of spatial information by territorial stakeholders.

TETIS carries out research on the characterisation and management of aquatic environments and their biodiversity. Satellite imagery – notably with very high spatial resolution – supplements the field measurement devices and provides an overview of the spatial structures and temporal dynamics of these environments (hydro-morphology of the watercourses, spatial distribution of habitats, etc.) while quantifying the pressures upon them. Spatial analysis and modelling are used to study the natural and anthropogenic phenomena involved (sediment dynamics, monitoring vegetation in rivers, lakes and lagoons; modelling of pressures/status).

TETIS is developing satellite and airborne methods for watercourses monitoring. Watercourse depths are mapped using optical imagery and airborne LIDAR measurements, in order to feed hydro-biological models simulating the functioning of habitats. Radar techniques (imagery, altimetry, interferometry) and associated mathematical methods are developed in collaboration with CNES (Centre National d’Études Spatiales) and ONERA (the French Aerospace Lab) to quantify watercourse surface variables (width, water level, slope and speed), and deduce the hydraulic parameters of the bottom and estimate flow rates.

TETIS is developing radar imagery (active microwave data) to quantify soil features such as moisture – information which is essential for physical modelling of hydrological processes or for combining surface-atmosphere parameters in a climate change setting.

In the agriculture domain, the study of plant water stress represents an important field of research for assessing agricultural production and enhancing water management. Research is focused on the evaluation of stress indices derived from aerial or satellite images or close-up infrared and thermal infrared imagery, and surface temperature measurements. Some research is also carried out on irrigated areas in the sub-Saharan region, focused on strategies for water access and use in a limited land setting.

As part of an integrated approach to public policies for territorial planning and management, TETIS and the Syndicat Mixte du Bassin de Thau carried out a research project on the analysis and design of territorial observatories. This work deals with spatial modelling of complex phenomena (urban spread, water management) and the role of information in governance processes: functions and uses of spatial representations in support of territorial consultation (3D models, mapping according to stakeholders), collection and legitimisation of local knowledge and know-how, analysis of the emergence and increasing autonomy of the territories, etc. TETIS is also undertaking work on the spatial sensitivity of methods for economic evaluation of flood risk management policies.
Spatialisation of environmental knowledge for the sustainable development of territories

The “Spatial Analysis for Development” Joint Research Unit – UMR ESPACE-DEV (IRD, UM2, UAG, UR) is developing and implementing innovative methodologies for the spatialisation of environmental knowledge for the sustainable development of territories, from data acquisition to the decision-making process. The aim is to contribute to the emergence of networks of environment observatories for sustainable development.

ESPACE-DEV is involved in the water domain through research and transfer programmes, notably in cooperation with developing countries:

- The programme “Flood flows and mass variations: the case of the Amazon Basin” aims at estimating, through spatial measurements, seasonal and inter-annual variations in the different reservoirs of the continental hydrological cycle and validating these estimates by comparison between different spatial sensors, using in situ measurements and/or modelling.

- The programme “Spatial data assimilation for the hydrological analysis of the Amazon Basin and short- and medium-term forecasting” aims to implement a rainfall-flow type hydrological model tailored to large tropical basins (cooperation between IRD and Brazilian institutions and universities).

- The programme “Extreme hydrological phenomena in French Guiana: forecasts, impacts and adaptation” is focused on one of the three large regions of the world in which the per-capita water supply is the highest. As a result of marked seasonal variations, French Guiana is hampered with extreme low-water or flooding phenomena, which can lead to breakdowns in drinking water supplies or severe high-water levels, which affects the habitats situated along river banks. The primary objective of the project is to develop operational forecasting and risk assessment tools for high- and low-water levels, to gain a better insight into the hydrological resources and characterise the associated extreme phenomena. The study aims to analyse the impacts of low-water level and flooding phenomena on communities and their living conditions and to evaluate the mitigation potential. The project will highlight potential adaptation strategies of local inhabitants (notably on the edge of the Maroni river). The project proposes to define and develop many vulnerability and resilience indicators and provide decision-making assistance.

- The programme “Alternatives to the evaluation of the ecological quality of watercourses in French Guiana: the contribution of remote sensing” involves the regular control of the quality of watercourses, subjected to increasing anthropogenic pressures (notably linked to illicit gold mining), in order to comply with the European Water Framework Directive. This type of surveillance of the rivers and other watercourses is difficult since it is impossible to carry out regular sampling throughout most of French Guiana due to access constraints. This project explores new methods for remote control of the state of sites that are hard to reach.

Hydrological dynamics and malaria in Amazonia

Water is generally associated with the presence of mosquitoes – including the species Anopheles, a malaria vector. But malaria transmission risk depends on a set of complex biological, ecological, climatic and societal mechanisms. In this respect, identifying and modelling the transmission mechanisms in time and space, in order to predict the level of “health risk”, remains a challenge. Research efforts are usually mainly limited to one vector (Anopheles darlingi; the most efficient one in Amazonia), to specific environmental, climatic and societal conditions, and at given temporal and spatial scales.

In close collaboration with entomologists and epidemiologists from French Guiana and Brazil, ESPACE-DEV focuses on the notion of spatiality, from the acquisition of data up to their interpretation, to develop applications and decision-support tools.

A study, based on wetlands mapping, showed that at the Amazon Basin scale, rivers and flooding areas hydrological dynamics constitute one of the main natural factors controlling malarial incidence. On a smaller scale, in French Guiana, significant correlations were found between An. darlingi abundance and hydrological dynamics on two sites studied out of three, while significant correlations with precipitations are found in only one case.

However, the role played by hydrological dynamics and their seasonal and annual variability on the epidemic and endemic character of malaria depends on regions and landscapes of Amazonia, according to still poorly understood processes. In an attempt to decipher the complexity of these processes, ESPACE-DEV studies the relationship between socio-environmental factors and malaria in the region of Manaus, following a multi-scale and multi-disciplinary approach. This project, funded by the Brazilian National Centre for Scientific and Technological Research (CNPq), involves Brazilian, American and French teams.

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Management of resources and uses: institutions, territories and societies

MISEEVA project: coast vulnerability to sea level rise

The MISEEVA project (Marine Inundation hazard exposure modelling and Social, Economic and Environmental Vulnerability Assessment in regard to global changes, 2008-11) is funded by the “Vulnerability, Environment, Climate” ANR programme.

The aim of this project, coordinated by the BRGM “Risks” department in Orléans, is to assess the social, economic and environmental vulnerability of the coastal zone marine submersion hazard provoked by climate change.

The EAU/NRE research unit, in partnership with the LAMETA JRU and SOGREAH (an engineering company), has set up and tested a methodology for the evaluation of economic impacts of a sea level rise linked to climate change, in the coming century in Languedoc-Roussillon. This evaluation, coupled with a model of risk spatial distribution, takes into account the impacts on both merchant and non-merchant types of goods (beaches, lagoons and wetlands, ground water) and on the different associated economic sectors, for various scenarios of public authorities reactions (anticipation and/or adaptation, refusal, laisser-faire, protection, withdrawal).

LAMETA was particularly involved in the study of hazard perception by populations, of behaviour types, and in the evaluation of public policies response types to better anticipate these changes.

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Remote sensing tools will enable linkage of the information received from the observation satellites with the biological and environmental features of the sites. From this information, the representativeness of downstream parts of the watercourses will be tested with respect to their general status. Based on this research, ESPACE-DEV will develop a method and a network for operational surveillance of the ecological quality of rivers in French Guiana.

ESPACE-DEV is mainly based in Montpellier, with secondary locations in French Guiana (IRD-UAG International Campus), La Reunion Island (Université de la Réunion), New Caledonia (IRD), Brazil (National Space Research Institute), Ethiopia (African Union), Gabon (Agence Gabonaise d’Observations et d’Études Spatiales) and Madagascar.

The expertise acquired by ESPACE-DEV on the use of remote sensing techniques for environmental monitoring benefits to several cooperation and transfer programmes. Hence, on the South American continent, the GUYAMAPA programme aims to develop indicators to monitor ecosystems, including the status of water resources, on the Oyapock basin, which marks the border between Brazil and French Guiana. Similarly, a bilateral cooperation programme between the Brazilian National Water Agency and the IRD Spatial Observatory of the Amazon Basin is running to develop a system for monitoring water levels in the Amazon Basin using radar altimetry. On the African continent, ESPACE-DEV is participating to the African environmental surveillance programme (AMESD), funded by the African Union Commission and the European Union. One of the orientations of the programme concerns navigation monitoring in the Oubangui branch of the Congo River and ecological monitoring of the Congo Basin.

Relationship between water, territories and societies in the Mediterranean Basin

The “Stakeholders, Resources and Territories in the Development Process” Joint Research Unit – UMR ART-DEV (UM3, CNRS, CIRAD) also involves Universities Montpellier I and Perpignan Via Domitia as associated partners and incorporates the local team of CEREQ (Centre d’Étude et de Recherche sur les Qualifications). ART-DEV mainly conducts research in the humanities and social sciences field, while favouring inter-disciplinary approaches, essentially bringing together geographers, economists, sociologists and political scientists. ART-Dev develops research on the reconfiguration of territories from economic, political and social standpoints, bringing into play both globalisation and local dynamics. It focuses analysis of this reconfiguration especially on the construction and mobilisation of an array of material and immaterial resources, through a diverse range of stakeholders.

For the past 20 years, ART-DEV has been carrying out multidisciplinary analyses of issues and challenges related to water management in the Mediterranean Basin (Maghreb, Lebanon, France, and the Iberian Peninsula). This research is focused on the relationships between water, territories and societies. Since 2004, it has been contributing to programmes launched by CNRS, the French Ministry of Environment and IRSTEA, on the “Water and Territories” topic (programme CNRS/SHS 2004-2005 “Water, Environment, Society”; programme CNRS/SHS Paris 2006-2009 to provide backing for research cooperation in the humanities and social sciences between North Africa and France; programme “Water and Territories” CNRS/IRSTEA/Ministry of Environment 2008-2011). Between 2003 and 2011, the unit was also part of the CNRS 2524 “Res-eau-ville” research group and several researchers are now collaborating with their North-American colleagues on linkages between urban projects and riparian ecosystems quality in Canada.
WASSERMed: water availability and security in Southern Europe and the Mediterranean

The WASSERMed European project (2010-2012) studies the environmental and social impacts of climate change, which threatens water resources and uses in the Mediterranean area.

Starting with an evaluation of the frequency and amplitude of extreme precipitations and changes in surface and ground water run-off, the project is also interested in the multitude of economic and social factors increasing the vulnerability of hydrological systems. The aim of WASSERMed is hence to contribute to:

- Reducing uncertainty about the impact of climate change on Mediterranean hydrology, by exploiting outputs from climatic models, by refining existing hydrological models and by developing tools for the simulation of scenarios on each of the five selected reference sites.
- Improving the regional evaluation of climatic effects on water resources and uses, through scientific experiments on the five pilot sites. The project focuses on the sensitive and vulnerable sectors of agriculture and tourism, particularly illustrative of the conflicts for water allocation and use.
- Providing a stronger knowledge base for water security by identifying and assessing water management policies, including virtual water exchanges. This should contribute, on the short term, to improving the resilience of Mediterranean anthropo-ecosystems to hydrological changes and, on the long term, to their adaptation to climate change.

Within this department, the “Renewable Resources Management and Environment” Internal Research Unit – UPR GREEN (CIRAD) aims to provide knowledge, methods and tools based on the modelling of complex systems, to support collective management processes and to improve stakeholders’ capacity to manage their socio-ecological system through a highly interdisciplinary approach (legal anthropology, agronomy, modelling, etc.)

The challenges are therefore threefold:
- To develop conceptual and technical tools to represent the socio-ecological systems in their multiple dimensions (economic, social, ecological, spatial and temporal) and to consider the broad range of stakeholders’ viewpoints (experts and non-experts) at different organisation levels;
- To develop approaches for using these tools, involving local stakeholders and scientists, in management processes ranging from collective apprenticeship and decision-making to negotiation;
- To assess the contributions of these approaches, initiatives and tools so as to analyse changes in the socio-ecological systems, the role of institutions and knowledge in these changes.

GREEN is developing several projects concerning water management in a multi-use and multi-user setting, as a follow-up to a companion modelling project (ComMod) for resilient water resource management concerning several Asian countries (Thailand, Vietnam, Bhutan, Philippines) (coordinated by GREEN in the framework of the “Challenge Program on Water and Food”, see page 61). The project “Management of sub-watersheds and governance of rainwater and small dams” was launched in 2010 and involves a comparative approach to watersheds in Ghana and Burkina Faso to analyse the role of the small reservoirs that have been installed.
Management of resources and uses: institutions, territories and societies

>ADAPTATION TO CLIMATE CHANGE

**CLIMAWARE: elaboration of strategies for adaptation to climate change – Case study on the management of the dams-reservoirs of the Seine Basin**

The CLIMAWARE project (2010-2013) brings together partners from Germany (Department of Hydraulic Engineering and Water Resources Management and Centre for Environmental Systems Research of Kassel University), Italy (Istituto Agronomico Mediterraneo di Bari) and French (IRSTEA and EPTB Seine Grands Lacs). Its objective is to draw up strategies for the adaptation of water management to climate change.

The French site studies the adaptation of the management of dams-reservoirs in the Seine basin to climate change. The objective is to assess the sustainability of current management methods in the short, mid and long terms and to propose to EPTB Seine Grands Lacs new management methods taking into account its objectives of water level regulation within the context of climate change.

This may result in real time management adaptations.

An initial phase of work consisted in setting up a semi-distributed hydrological model on the basin scale, taking into account the specificities of the various tributaries. Calibrated on real time on around 25 flow stations, the model was then fed with disaggregated outputs from climatic models (temperatures and precipitations). Results comparison between the reference period (1961-1990) and a future middle-century period (2046-2065) shows a downward trend of the level and duration of low water. Trends for high water level are much less significant.

The viability of current management strategies will henceforth be evaluated in this context and various adaptation options will be tested.

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For more information: www.uni-kassel.de/fb14/wasserbau/CLIMAWARE
▲ The Marne reservoir-lake.

>INTEGRATED WATER RESOURCE MANAGEMENT

**Water and hydro-systems governance in North Africa and the Near-East**

GREDA studies water and hydro-systems governance mainly in North Africa and the Near-East and secondarily in South-East Asia and the Andes, in collaboration with various local partners and the International Water Management Institute.

In Egypt, GRED is interested in collective actions in the Nile delta, at the level of secondary and tertiary irrigation channels (mesqas), in the relationships of the State with its technical ministries and with farmers, as well as in the elaboration of water public policies.

In Morocco, research is carried out on several scales around the governance of water and land resources. A first investigation area concerns mountain and oasis agriculture in South Morocco and focuses on the role of irrigated lands in family and farm economies. Particularly, the collective management of khettaras (draining galleries similar to qanâts in the Middle-East) is a main centre of interest.

Another investigation area concerns the comparison of radio-concentric land systems in Saïs (South of Meknès in Morocco), in France (Montady) and in Egypt. Finally, GRED also analyses, at the regional hydrographic basin scale, a recently introduced system of hydrographic basin agencies, supposed to apply integrated management principles, as well as the implementation of the “Plan Maroc Vert” (“Green Morocco Plan”) and its impact on the irrigated area of Tadla.

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▲ Draining gallery in Morocco.
Water management in mountain catchments has several specificities such as the importance of the run-of-river management, the high number of inter-basin transfers and agricultural water use strategies conceived on several bioclimatic levels and structured around a well-developed hydraulic infrastructure.

The Quito supply basin in Ecuador is an example: situated between 2,000 and 5,900 meters in altitude, spreading over 5,000 km², it is facing various complex issues representative of mountain basins. The population density is high, there is a strong demographic growth, increasing the demand for basic services and reducing agricultural land use to the profit of uncontrolled urbanisation. Water demand, involving several competing sectors, greatly overpasses the available resource. Large water transfers are operated from “páramos”, lands situated over 3,500 m in altitude, whose soils filter and store water from rainfall and glaciers melting, regulating water flows all year long. Global warming, demographic pressure and the energy crisis lead to their overexploitation and question their sustainability. Recently, the government decided to move towards integrated management of the water resource per hydrographic entity.

Scientists from G-EAU thus set up in Quito in order to develop scientific collaborations with Ecuadorian institutions and university to support the current changes. Activities are developed on five themes: (1) state of the water resources, spatial and altitudinal distribution and evolution during the past 50 years, (2) identification and recent evolution of water demand according to different scenarios of global change, (3) failure risk of the existing water distribution system in the Quito basin, (4) construction of simulation models for decision-making support, for fair sharing and future planning of water resources (5) ecological impacts of hydraulic pumping or storage installations in mountain areas. The first three themes are being developed in collaboration with the National Institute of Meteorology and Hydrology and the National Polytechnic School. The fourth is being carried out jointly with the Municipal Drinking Water and Sanitation Enterprise and the IRSTEA centre of Lyon, through the supervision of a Master’s degree student.

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Management of resources and uses: institutions, territories and societies

**INTEGRATED WATER RESOURCE MANAGEMENT**

**Participative and multi-level management of water in Ghana and Burkina Faso**

Since 1992, the principles of integrated water management have gradually been imposed in water policies. The participation of the different stakeholders involved in decision-making processes has become a principle in the elaboration of decentralised public policies. Multi-level water management, which is nowadays fully accepted, raises questions about tools to regulate the social, economic and ecological effects, which may be contradictory depending on the scale considered, sector prioritisation and involved stakeholders. The difficulty is to draw up consultation methods allowing expression of these various points of view, so as to come to institutional and technical innovations which are accepted by all.

Since 1998, within the multi-institutional Companion Modelling (ComMod) framework, the GREEN research unit has been developing participative modelling approaches to support decision-making processes and the production of knowledge on the management of socio-ecological systems and renewable natural resources. For instance, GREEN develops activities in the Volta area, in the context of the “Challenge Program on Water and Food” - phase 2 (see page 61), in collaboration with the International Water Management Institute and the Water Resource Commission, the Permanent Secretariat of the Support Programme for the Integrated Management of Water Resources. The main objective of the “Sub-basin management and governance of rainwater and small reservoirs” project is to facilitate the interactions between the different levels of management and decision-making in Burkina Faso and Ghana, so as to make the integrated management of water resources effective. For this purpose, a ComMod initiative is being developed by the stakeholders from local and intermediate levels together with political decision-makers.

Through dialogue, the objective is that everyone be informed about constraints of each others, to build new modes of interaction in the production of management rules and standards. In Burkina Faso, multiple water management structures exist on different scales. GREEN therefore supports local water committees, kinds of multi-stakeholders platforms at the small catchment level, which have been created but are not very functional yet. In Ghana, where these intermediate platforms do not exist, GREEN is supporting the emergence of new forms of multi-stakeholders organisations likely to take into account the different management and decision-making levels. Participative workshops are organised for this purpose (role playing, multi-agent systems, etc.). In time, innovation will reside in the implementation of new multi-scalar modes of interaction between the stakeholders involved in the integrated management of water resources.

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**AQUADEP: drinking water governance at local level**

The AQUADEP project studied the drinking water governance at the district level. Its main objectives were the characterisation, evaluation and support of drinking water policies. It sought to gain a better knowledge of these policies and to clarify the terms of the debate about the institutional framework of drinking water management, notably with regard to territorial scale and governance. At the same time, a more targeted “research-intervention” on the information and steering system of territorial governance (indicators system) was developed to support operational stakeholders in their decision-making process.

The main outputs of the project were: a typology of drinking water policies drawn by the Conseils Généraux (General Councils); the characterisation of local drinking water governance in a few districts representative of the various situations previously identified; a comparison with the situation in Italy and Denmark; methodological proposals for information systems and indicators.

AQUADEP is an interdisciplinary 3 years research project (2008-2011), funded by the “Water and Territories” programme of the French Ministry of Environment, CNRS and IRSTEA. It brought together 12 researchers and teachers-researchers from five teams (ENGEES: École nationale du Génie de l’Eau et de l’Environnement de Strasbourg – IRSTEA in Strasbourg, G-EAU and ART-Dev in Montpellier, the “Réseaux” research unit of IRSTEA Bordeaux and the CERTOP research unit of CNRS/Université Paul Sabatier in Toulouse). Remi Barbier from ENGEES-IRSTEA has coordinated the project.

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The current landscapes evolution is characterised by an inter-penetration of territories, which poses a number of problems to water managers. The French and Quebecois public authorities are aware of the limits of the planning instruments intended to control urban spread. The public or associative organisations in charge of water policies raise questions about the scope of these policies: what is their real impact on the evolution of land use at the catchment level? In what ways do the town and country planning policies interact with water policies? What are the conditions required for the “de-compartmentalisation” of policies, which are so often at odds with each other, in a context of local authorities’ empowerment, increased territorial competition, globalisation and as a corollary, interrogations about the role of the State in the management of natural resources?

These questions are central to the research project IDEAUX. Its main starting point is a critical examination of the recent evolution of the planning paradigm in France and Quebec. The project methodological framework is based on a comparative approach of the processes at the heart of development policies. This Franco-Quebecois programme is based upon a partnership between the private company SOGREAH consultants (Groupe Artelia) and several French and Quebecois public organisations. It is funded by the “Waters & Territories” programme (2008) of the French Ministry of Environment.

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IDEAUX: water, development, town planning and urbanisation policies integration for the protection of aquatic environments in France and Quebec
The Challenge Program on Water and Food (CPWF) works on the links between water, food, and poverty in developing countries.

International Cooperation and Partnerships
Research laboratories in the Languedoc-Roussillon region share many programmes with each other and with other scientific partners in France, Europe and the rest of the world, especially countries in the South. This has been underlined in several of the previous chapters. However, given the extensive diversity of the water sector and its crucial importance in the day-to-day life of human societies, the labs are also open to other economic and public stakeholders at regional, national and international level. Hosting the leading French scientific community of multi-disciplinary water specialists, the region has seen the arrival or emergence of several joint organisations fostering many discussions and exchanges. These organisations can be grouped into two categories: those working in the economic sector and involved in policy-making – the State, its agencies and local authorities – and those representing and managing scientific activities at national or international level.

Actions with the economic sector are being developed with the support of local authorities and the government through two competitiveness clusters: the “Water” and “Risks” clusters. The regional water sector is especially rich in innovative SMEs, while at the same time benefiting from the expertise and representativeness of major French groups whose international presence is a particularly useful asset. Two interfacing structures complete this web of organisations: Transferts LR, facilitating contacts between SMEs and laboratories and VERSeau Développement, mediating between scientific labs, public decision-makers, international institutions and economic relays, especially the competitiveness clusters and water companies, most of whom are part of the regional SWELIA organisation.

The second set of partnerships pursues scientific goals with scientific associations having chosen to set up their headquarters in Montpellier and/or in which the regional scientific community is highly involved. This is the case of the International Water Resource Association (IWRA) and the International Association of Hydrological Sciences (IAHS), at the international level, and of the Association Française pour l’Eau, l’Irrigation et du Drainage (AFEID), at the national level. Furthermore, two major international organisation programmes are entirely or partly coordinated from Montpellier: the Challenge Programme on Water and Food of the CGIAR (Consultative Group for International Agricultural Research) and the International Hydrology Programme (IHP) of UNESCO.

Pierre Chevallier & Marie Mojaisky
(Association VERSeau Développement)
International Cooperation and Partnerships

“Water” competitiveness cluster

Both at regional and international levels, the quality and quantity of available water resources depend on global changes, with a rise of climatic uncertainty and anthropogenic pressures to produce more food, energy, etc. These considerations led to the creation of a technology-centred, worldwide “Water” competitiveness cluster. The main goal of this cluster is to assess and manage water resources, both from the quantitative and qualitative points of view, using the associated eco-technologies, for the benefit of all uses: drinking water supplies, sanitation, farming and industrial uses, energy and leisure activities.

Thus, the “Water” Competitiveness Cluster is active at different levels, linked to the various stages of the water cycle (from water drawing to its return to the natural environment after different uses). Four strategic areas are targeted:

1. Identification and use of water resources.
2. Concerted management and uses in contexts with high pressure on water resources.
3. Reuse of water from all sources.
4. Institutional and societal approaches in terms of stakeholders and decisions.

In order to fit to markets of water products/services and water demand, characterised by a high internationalisation, and to changing regulations, the cluster has adopted a global outlook. 2015 will see the term of the European Water Framework Directive and it is also the deadline to achieve the United Nations Organisation’s Millennium Development Goals. By 2015, the ambition of the “Water” competitiveness cluster is to effectively contribute to the “better management of water resources and uses subjected to global changes” through new, more suitable and integrated water products/services.

The “Water” cluster was approved in May 2010 by the French Interministerial Committee on Local Development. It includes the Languedoc-Roussillon, Midi-Pyrénées and Provence-Alpes-Côte d’Azur regions. It leads the coordination with the two other water clusters in France: HYDREOS (continental water management) in Alsace and Lorraine regions and DREAM (water and environments) in Centre region.

The “Water” cluster seeks to create value through innovative projects in the field of water use and management (economic growth, employment, creation and development of SMEs, SMIs and intermediate-sized enterprises). It gathers skills, questions and answers, in order to provide suitable solutions to the many issues relating to water resource management. It promotes the involvement of water stakeholders in international water market dynamics.
“Risks” cluster: designing pragmatic solutions to risk-management problems

The “Local Vulnerability and Risk Management” cluster, also referred to as the “Risks” cluster, has supported the emergence of collaborative Research and Development projects since 2005 in the Provence-Alpes-Côte d’Azur and Languedoc-Roussillon regions. This cluster addresses issues linked to chronic and accidental hazards in specific areas, from prevention to post-crisis management, and hence covers all stages of the risk wheel.

Many projects labelled by the “Risks” cluster (and funded by national, regional and local organisations), deal with the risk of flooding. For example, the HYDROGUARD project (see page 42), developed by the SME ESECO System and supported by the French Inter-ministerial Single Fund (FUI), aims to develop a reliable, autonomous and automatic system for monitoring waterways and the coastline. This system will allow local authorities to ensure sustainable management of water bodies and areas. It relies on an infrastructure fitted with equipments to monitor and continuously check the water resource and coastal erosion. Such equipments are able to make local forecasts based on scientific models, hence providing information particularly useful upon crisis (floods, accidental pollution, winter storms, etc.).

Two other projects, linked to flooding and submersion, have recently received support from FUI. The first project, KRHU (standing for “karst, runoff and humidity”), led by Predict Services, seeks to improve karstic flooding forecasts by providing on-call services (forecasters, analysts, etc.) with a crisis management tool based on relevant ground saturation and karst indicators. The second project, LITO-CMS, led by BRL Ingénierie, focuses on forecasting and real-time management of coastal flooding and submersion. It aims to alleviate local authorities’ current lack of available and precise information about tidal surge risks. The impact of tidal surges on coastal river flows is not taken into account in current services.

Transferts LR: fostering water innovation in the Languedoc-Roussillon region

Created in 2005 by the regional authority and the government, and today supported by Europe and local general councils, the Transferts LR association contributes to the competitiveness of Languedoc-Roussillon firms through innovation and technology transfer. Its main activity is to foster innovation, technology transfer and the integration of new know-how and skills in regional companies. It networks with all economic development stakeholders.

Several Transferts LR actions concern water and involve research laboratories and firms of all sizes, some of which belong to the SWELIA group (group of companies working in the water sector) and/or are members of the “Water” competitiveness cluster. The association’s actions target:

- The knowledge, prevention and management of hydrological, health and water pollution risks;
- The concerted management of water resources (including unconventional resources) and their uses, weather forecasting tools and combinations of indicators for the characterisation and monitoring of water bodies and events;
- The water treatment, purification and sanitation by-products reuse processes;
- Transport networks;
- Water and energy.

Pilot experiments are carried out in laboratories, technology halls (LBE, EMA, UM2), specialised institutes (Risk Sciences Institute in Ales) or private centres of excellence (IBM Water management) in Languedoc-Roussillon. Methodologies are often developed in real operating conditions, on site or in a public facility. They involve the French Water Agency, the government offices concerned and local authorities’ technical service providers.
Transferts LR provides concrete, multi-disciplinary and lasting support for the setting up and performance of innovative technological projects. It takes part to firms’ early project design, it establishes relations with the concerned research laboratories, it sets up and monitors projects. The products/services developed have regional, national and European applications. It belongs to the “Europe Enterprise” network (over 600 members), which is particularly helpful when looking for European partners and setting up business meetings with specialised companies in other European districts. Transferts LR provides scientific advice to project funders for technical evaluation of the projects.

The dynamic approach of the region’s very small and small to medium-sized enterprises and the synergy between research laboratories and major groups give rise to tangible, integration-focused projects offering high added value and meeting users’ needs. They correspond to substantial investments (amounting to between tens of thousands and several million Euros), and are carried out with the support of French regional authorities (notably the Languedoc-Roussillon region), Oséo, the European Regional Development Fund and the government (FUI fund, Ecol Industrie and ANR).

Between November 2010 and November 2011, this support targeted ten collaborative projects (with a duration of 24 to 36 months and investments of 1.2 to 4 million Euros), headed by consortiums of various sizes concerned with the development of water eco-technologies, water management (approved by the “Water” cluster), risks of flooding and tidal submersion (approved by the “Risks” cluster), and marine environment biodiversity monitoring (approved by the “Sea” cluster). Other projects, led outside the clusters, concern water treatment, protection of water abstraction systems, and reuse of treated waste water.

VERSeau Développement: an interfacing and dedicated coordination association

Founded in 1983, the VERSeau Développement association gathers members from research organisations, industries and local authorities, working together to foster projects focusing on water management (institutional, technical and legal aspects).

VERSeau Développement aims to strengthen and improve water management through key missions:
- Carrying out consultation and facilitation missions between the scientific, industrial and public partners;
- Contributing to the running and promotion of scientific and technological networks;
- Putting to good use the results of research or development programmes;
- Helping with the implementation of public water policies;
- Performing expert studies and providing advice and training.

These missions are accomplished through activities of management and coordination of networks and projects and programmes in the field of water, through the provision of expertise, the organisation of events, etc.

VERSeau Développement gives support to local authorities (and government offices) for the design and setting up of public policies, to local companies and industries working in the water sector and to research and training institutes. To do so, it carries out expert studies, search for partners, supervision of trainees and leads projects such as the promotion of the Languedoc-Roussillon sanitation network quality charter.

VERSeau Développement calls for its international experience for the implementation of European cooperation projects, especially in the Mediterranean basin, Central Europe, Caucasia and Central Asia, for the support of the decentralised cooperation of the Hérault General
Council (in Tunisia and Morocco) and for the animation of scientific international networks.

In 2008, VERSeau Développement organised the XIIIth World Water Congress of IWRA (International Water Resources Association, see page 59) in partnership with the Institut Languedocien de Recherche sur l'Eau et l'Environnement and ENJOY Montpellier, and in association with international private, scientific and institutional stakeholders. VERSeau has also hosted the executive office of IWRA since April 2010.

IWRA: International Water Resources association

IWRA is an international network of multidisciplinary experts on water resources. This non-profit, non-governmental, educational organisation was established in 1971. IWRA provides a global forum for professionals, students, individuals, corporations and institutions concerned with the sustainable use of the world’s water resources. The objective of IWRA is to improve the understanding of water issues through education, research and information exchange among countries and across disciplines. IWRA is deeply committed to the sound management of water resources thanks to a better understanding of the physical, ecological, chemical, institutional, social and economic aspects of water.

To this end, the association:
- Provides an international forum for water resource issues;
- Performs advanced research on water resources;
- Promotes water education notably by improving global access to relevant data and information;
- Enhances the quality of knowledge used in decision-making;
- Improves exchanges of information and expertise;
- Networks with other organizations to advance common interests and goals.

Since 1973, the IWRA World Water Congress has been held every three years in different cities across the world. Each edition has a central theme linked to current water issues. Thus, the XIVth World Water Congress was organised in Porto-de-Galinhas (Brazil) in 2011 and focused on "adaptable water management". The next edition will be co-organised in 2014 with the University of Granada (Spain).

Since 1975, "Water International" is the IWRA’s official journal, published by an international publisher since 2008. The journal is a key source of information in terms of research and international policy on water resources. Articles and technical memos in "Water International" focus on water management, policy and governance and target a broad inter-disciplinary readership. The journal keeps members informed and connected to a network of academic and operating members across the entire world by publishing important information from conferences, reviews, books, discussions, etc.

IWRA recognises the major contribution to water management made by organisations, professionals and researchers. This is why, during the IWRA World Water Congress, individuals, authors and organisations receive awards for their contribution to improving the state of water resources in the world. **
IAHS: International Association of Hydrological Sciences

The International Association of Hydrological Sciences, IAHS, is a scientific organisation serving hydrological sciences and the international community of hydrologists. Founded in 1922, the association has over sixty national committees and over 5,000 individual members from 130 countries. IAHS goal is to promote hydrology as an earth science and a founding pillar of water management. Its main activities are to initiate and coordinate international research on hydrological issues, to provide a medium for discussing and publishing hydrological research, to support hydrological sciences in developing countries and to train hydrologists.

The association’s ten international commissions focus on various aspects of the hydrological cycle, on water resources and on specific technologies. IAHS publishes the "Hydrological Sciences Journal" in English and French (8 issues a year) and conference proceedings as part of the "Red Book Series" (350 volumes published). Many Montpellier-based hydrologists have become involved in IAHS and continue to work for the association. Currently, for example, Eric Servat (HSM) is the President of the International Commission on Surface Water, Frédérique Seyler (Espace-DEV) is the Vice-President of the International Commission on Remote Sensing and Gil Mahé (HSM) is an associate member of the International Commission on Water Resources Systems.

AFEID: Managing water for sustainable agriculture

The French Association for Water, Irrigation and Drainage (AFEID) is a non-profit, general-interest association created in 1954. AFEID represents French expertise on issues of water supply and rural development. Its members are individual experts and organisations: farming professionals, regional development structures, research organisations, R&D offices, associations and foundations.

AFEID offers an ideal forum for exchanging ideas about water supply and rural development issues. The association contributes to debates on water-related farming and environmental challenges by regularly organising regional or national meetings and international conferences.

AFEID is the French chapter of the International Commission on Irrigation and Drainage (ICID). It takes part in the commission's working groups and annual conferences, and contributes to publications of ICID "Irrigation and Drainage" review. As part of the Partenariat Français pour l’Eau (French Water Partnership), AFEID helps to prepare and expose the French position before major authorities and at international conferences, especially World Water Forums.

AFEID is committed to an approach based on technical cooperation together with the Agence Française de Développement (French Development Agency) and the French Ministry of Foreign and European Affairs within the framework of public aid for development.

In France, AFEID works on common themes with the Scientific and Technical Association for Water and the Environment, the Société Hydrotechnique de France (French Hydrotechnical Association) and the French Water Academy with the support of the French Ministry of Ecology, Sustainable Development, Transport and Housing and the French National Agency for Water and Aquatic Environments.

The association’s organisation is based on a technical committee divided into thematic working groups that guide the association’s thinking and work: the right water quality for the right use; environmental engineering for restoring waterways; economic, financial and fiscal instruments for water management; the future of water under global changes pressure; participatory management of irrigation and co-engineering; experience sharing about irrigation system management; underground water resources management.

Research on water in agricultural production systems at CGIAR

Since 2010, Montpellier has hosted the headquarters of the Consortium of the CGIAR (Consultative Group on International Agricultural Research). CGIAR is a strategic partnership gathering 64 public and private donors, supporting 15 international centres working in collaboration with hundreds of government, civil society organisations and private businesses.
around the world. Currently, research on water in agricultural production systems is mainly addressed through two CGIAR programmes: the CPWF (Challenge Program on Water and Food), running since 2002 and the “Water, Land and Ecosystems” programme, implemented in 2012.

**CPWF: Challenge Program on Water and Food**

Since 2002, the CPWF has been exploring the link between water, food and poverty in developing countries. This programme fosters innovation in the field of water, with the goal of reducing poverty, improving food security, strengthening rural communities and maintaining ecosystem services. To fulfil this objective, the CPWF uses a novel research and development approach that brings together scientists, development specialists, policy makers and rural communities in various water basins.

The CPWF has always produced many innovations, notably in ten “pilot” basins including the Andes and São Francisco in South America; the Limpopo, Nile and Volta in Africa; the Ganges, Indus, Karkheh, Mekong and Yellow River in Asia. These basins cover 13.5 million km² and accommodate roughly 1.5 billion people, half of whom are among the poorest in the world.

In 2011, the CPWF published the conclusions of a vast study on water, food and poverty in these ten basins. According to Simon Cook, director of the CRP5 programme, “the most surprising discovery is that, in spite of the pressure exerted on our basins today, there are some relatively direct ways to meet our development needs and alleviate the poverty of millions of people without exhausting our most precious natural resource”.

Indeed, there are enough resources to meet the population needs up until 2050, but the path towards sustainability depends on policies and institutions, especially with respect to benefit-sharing.

Below is a summary of some of the major findings of this study:

- There is only a limited connection between poverty and water. The challenge is much more complex than water scarcity alone. Water scarcity leads to populations competing for water and to the unequal sharing of the products and services from basins (water, food, energy and regulation of ecosystem services).
- Considerable gains in farming productivity can be achieved in rain-fed agriculture zones, especially in Africa. The CPWF has observed that only 4% of available water in these areas is used for agriculture and breeding. With modest improvements in Sub-Saharan Africa, two to three times more foodstuffs could be produced. Similarly, an increase in productivity is not only dependent on improving technology, but also on improving markets (infrastructures, access, etc.).
Water resources: preservation and management

FRIEND: Flow Regimes from International and Experimental Network Data

FRIEND is the flagship programme of UNESCO's International Hydrological Programme (IHP). It is shared between roughly ten regional groups across the world and involves over 100 participating countries. The goal is to promote collaborative international research in order to develop a better understanding of hydrological variability and similarity across time and space through the mutual exchange of data, knowledge and techniques at regional level. The advanced knowledge of hydrological processes and flow regimes gained through FRIEND helps to improve the methods applicable in water resources planning and management.

The major research topics studied in each FRIEND group vary according to regions and mainly concern erosion and sediment transport, eco-hydrology, low flows and underground waters, hydrological modelling, the impact of global change on flow regimes and water resources. A shared database has been set up in each regional group and is accessible to associated researchers, via the websites developed. Various activities have been developed as part of FRIEND under the aegis of UNESCO: scientific workshops, international conferences, training, scientific discussions, etc.

Hydrologists of the regional scientific community take part to this major...
international programme. Jean-François Boyer (HSM) coordinates the databases of several regional groups: MEDFRIEND (Mediterranean basin), FRIEND-AOC (Central and Western Africa), and FRIEND AMIGO (Latin America and the Caribbean). HydroSciences Montpellier (Éric Servat then Gil Mahé) has been in charge of the overall coordination of MEDFRIEND since 1999. HSM has also been in charge of the technical and financial coordination of FRIEND-AOC for almost ten years and continues to act as a key partner for this community of African researchers. Finally, Éric Servat chaired the FRIEND Inter-Group Coordination Committee from 2002 to 2006 and continues to sit on the committee together with Gil Mahé.

The “Water for All” Chair for universal access to water and sanitation

Thousands of cities with several thousand inhabitants suffer from badly managed urban water services. Lack of knowledge, especially with respect to the management of urban water and sanitation services, can prevent the Millennium Development Goals from being reached in the poorest countries. Based on this observation, a “Water For All” education and research chair was set up by the Suez Environnement Foundation and ParisTech in June 2009.

Hosted by Institut de France and managed by two of the ParisTech schools (AgroParisTech and Mines ParisTech), the chair was born from a wish to initiate a long-term partnership on the development of access to water and sanitation in developing, emerging or transitional countries.

The “Water For All” chair promotes the spread of knowledge, know-how and operational practices for managing urban drinking water and network sanitation in these countries. To do so, the chair delivers an AgroParisTech International Executive Master training course in Montpellier (see page 68), alternatively in French and English. It aims at strengthening managers’ skills and initiating changes in urban water services. Another of the chair’s roles is to create a network of auditors and professionals largely involved in all stages of the training course.

The chair is also involved in setting up an international reference centre by linking the training course to a research programme dedicated to developing access to water and sanitation. The centre’s scientific structure and content are designed to tie in with the Mines ParisTech and AgroParisTech research units (Scientific Management Centre, UMR G-EAU, etc.). The research axes focus on:

- Facilitating universal and sustainable access to water and sanitation services;
- Analysing the conditions for accessing these services;
- Studying the governance of drinking water and sanitation services in developing and emerging countries.

Thousands of cities with several thousand inhabitants suffer from badly managed urban water services. Lack of knowledge, especially with respect to the management of urban water and sanitation services, can prevent the Millennium Development Goals from being reached in the poorest countries. Based on this observation, a “Water For All” education and research chair was set up by the Suez Environnement Foundation and ParisTech in June 2009.

Hosted by Institut de France and managed by two of the ParisTech schools (AgroParisTech and Mines ParisTech), the chair was born from a wish to initiate a long-term partnership on the development of access to water and sanitation in developing, emerging or transitional countries.

The “Water For All” chair promotes the spread of knowledge, know-how and operational practices for managing urban drinking water and network sanitation in these countries. To do so, the chair delivers an AgroParisTech International Executive Master training course in Montpellier (see page 68), alternatively in French and English. It aims at strengthening managers’ skills and initiating changes in urban water services.
The different research units and teams appearing in this document are listed in the table below.

1. The resource: identification, functioning, mobilisation
2. Conservation and restoration of water quality
3. Management of water resource and uses: institutions, territories and societies

Each team’s “main” topics are indicated in (*) in the table below.

<table>
<thead>
<tr>
<th>Units</th>
<th>page</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>UMR ART-Dev – Actors, Resources and Territories in the Development Process (CNRS, UM3, CIRAD, UM1, UPVD)</td>
<td>48</td>
<td>●</td>
<td></td>
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<tr>
<td>Genevieve Cortés</td>
<td></td>
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<tr>
<td>UMR EMMAH – Mediterranean Environment and Agro-Hydrosystems Modelling (INRA, UAPV)</td>
<td>14</td>
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<tr>
<td>Liliana Di Pietro</td>
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<td>UMR ESPACE-DEV – Spatial Analysis for Development (IRD, UM2, UAG, UMR)</td>
<td>47</td>
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<tr>
<td>Frédéric Huynh</td>
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<tr>
<td>UMR G-EAU – Water Management, Stakeholders, Uses (AgroParisTech, IRSTEA, CIHEAM-IAMM, CIRAD, IIRD, Montpellier SupAgro)</td>
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<tr>
<td>Patrice Garin</td>
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<td>UMR GM – Montpellier Geosciences (CNRS, UM2)</td>
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<tr>
<td>Jean-Louis Bodnier</td>
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<tr>
<td>UMR GRED – Governance, Risk, Environment, Development (IRD, UM3)</td>
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<tr>
<td>Francis Laloe</td>
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<td>UMR HSM – Montpellier HydroSciences (CNRS, IIRD, UM1, UM2)</td>
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<tr>
<td>Éric Servat</td>
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<tr>
<td>UMR IEM – European Membrane Institute (CNRS, ENSCM, UM2)</td>
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<tr>
<td>Philippe Miele</td>
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<tr>
<td>UMR ITAP – Information-Technology-Environmental Analysis-Agricultural Practices (IRSTEA, Montpellier SupAgro)</td>
<td>28</td>
<td>● ● ●</td>
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<tr>
<td>Tewfik Sari</td>
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<tr>
<td>UMR LAMETA – Montpellier Laboratory of Theoretical and Applied Economics (CNRS, INRA, Montpellier SupAgro, UMR1)</td>
<td>44</td>
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<tr>
<td>Jean-Michel Salles</td>
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<tr>
<td>UMR LISAH – Laboratory for the study of Interactions between Soils, Agrosystems and Hydrosystems (INRA, IIRD, Montpellier SupAgro)</td>
<td>13</td>
<td>● ● ●</td>
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<tr>
<td>Jérôme Molénat</td>
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<tr>
<td>UMR TETIS – Territories, Environment, Remote Sensing and Spatial Information (AgroParisTech, CIRAD, IRSTEA)</td>
<td>46</td>
<td>● ● ●</td>
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<tr>
<td>Jean-Philippe Tonneau</td>
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<tr>
<td>UMS OREME – Mediterranean Environmental Research Observatory (CNRS, IIRD, UM2)</td>
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<tr>
<td>Nicolas Arnaud</td>
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<td>UPR GREEN – Management of Natural Resources and the Environment (CIRAD)</td>
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<tr>
<td>Martine Antona</td>
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<td>UPR EAU/NRE – Water: New Resources and Economics (INRA)</td>
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<tr>
<td>Jean-Christophe Maréchal</td>
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<td>UPR LBE – Environmental Biotechnology Laboratory (INRA)</td>
<td>29</td>
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<tr>
<td>Jean-Philippe Steyer</td>
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<tr>
<td>UPR LGEI – Industrial Environment Engineering Laboratory (EMI)</td>
<td>12</td>
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<tr>
<td>Miguel Lopez-Ferber</td>
<td></td>
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<tr>
<td>US Analysis – Water, Soils and Plants Analyses (CIRAD)</td>
<td>31</td>
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</tr>
<tr>
<td>Daniel Babre</td>
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</tbody>
</table>
Agropolis International, through its affiliated institutions, universities and engineering schools (and specialised vocational training institutes) offers a complete range of training programmes, with over 80 degree programmes (from the baccalaureate – high school leaving certificate – 2-years post-secondary to 8-years post-secondary: technician, engineer, bachelor’s degree (licence), master’s, specialised master’s, PhD, etc.). The tables below outline the training-education courses related to “Water”. They specify the diploma levels, the title of the training and the institutions where it is delivered.

### Programmes entirely focused on the theme of “Water”

<table>
<thead>
<tr>
<th>Level</th>
<th>Degree</th>
<th>Title</th>
<th>Institutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bac +3</td>
<td>Licence (BSc)</td>
<td>Life and Earth Sciences - Earth and Water focus</td>
<td>UAPV</td>
</tr>
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<td></td>
<td>Licence professionelle (BSc with professional scope)</td>
<td>Automated Management of Water Treatment Systems</td>
<td>UM2, Montpellier SupAgro, EPLEFPA (Lozère)</td>
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<tr>
<td>Bac +5</td>
<td>Master (MSc)</td>
<td>Water – “Water and Society” Speciality</td>
<td>AgroParisTech, IAMM, Montpellier SupAgro, UM1, UM2, UM3</td>
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<tr>
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<td></td>
<td>Water – “Water and Agriculture” Speciality</td>
<td>AgroParisTech, Montpellier SupAgro, UM2</td>
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<td></td>
<td>Water – “Water and Resources” Speciality</td>
<td>UM2</td>
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<td></td>
<td>Water – “Contaminants, Water and Health” Speciality</td>
<td>UM1, UM2</td>
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<td>Hydrogeology, Soils and Environment</td>
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<td>Ingénieur (Engineering degree)</td>
<td>Agronomy Engineer - Option “Management of Water, Cultivated Lands and the Environment”</td>
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<td>Polytechnic Engineer - Water Sciences and Technologies</td>
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<td>Bac +6</td>
<td>Mastère spécialisé (Specialised MSc)</td>
<td>Water Management</td>
<td>AgroParisTech</td>
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<td></td>
<td></td>
<td>Water for All</td>
<td>AgroParisTech</td>
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### Programmes focused on other themes having a water component

<table>
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<th>Level</th>
<th>Degree</th>
<th>Title</th>
<th>Institutions</th>
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<tr>
<td>Bac +2</td>
<td>DUT (University diploma of technology)</td>
<td>Biological Engineering, Option Environmental Engineering</td>
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<td></td>
<td>Chemistry: Chemical Analysis Applied to the Environment</td>
<td>UM2</td>
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<tr>
<td>Bac +3</td>
<td>Licence (BSc)</td>
<td>Geography</td>
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<tr>
<td></td>
<td></td>
<td>Biology</td>
<td>UNîmes</td>
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<tr>
<td></td>
<td></td>
<td>Geosciences, Biology, Environment</td>
<td>UM2</td>
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<tr>
<td></td>
<td></td>
<td>Earth &amp; Environmental Sciences</td>
<td>UPVD</td>
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<tr>
<td></td>
<td></td>
<td>Biology, Ecology</td>
<td>UPVD</td>
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<tr>
<td></td>
<td>Licence professionelle (BSc with professional scope)</td>
<td>Sustainable Management and Planning of Territories and Resources</td>
<td>UPVD</td>
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<tr>
<td></td>
<td></td>
<td>Chemical Analysis Applied to the Environment</td>
<td>UM2</td>
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<tr>
<td></td>
<td></td>
<td>Environmental Impacts and Risks Professions</td>
<td>UNîmes</td>
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<td></td>
<td></td>
<td>Dismantling, Waste and Depollution, Control of Industrial Risks Professions</td>
<td>UNîmes</td>
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</table>
...programmes focused on other themes having a water component

<table>
<thead>
<tr>
<th>Level</th>
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<th>Title</th>
<th>Institutions</th>
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<tr>
<td>Bac +5</td>
<td>Master (MSc)</td>
<td>Engineering and Territorial Management</td>
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<td></td>
<td>Rural Societies, Territories and Natural Resource Management in the Mediterranean</td>
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<td>Agricultural Management and Territories</td>
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<td>ICTS for the Environment</td>
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<td>Territories and Societies, Planning and Development</td>
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<td></td>
<td>Sustainable Development and Planning</td>
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<td></td>
<td>Geosciences</td>
<td>UM2</td>
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<td></td>
<td>Ecology-Biodiversity, specialities: Biodiversity Evolution, Environment and Sustainable Development</td>
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<tr>
<td></td>
<td></td>
<td>Marine Geosciences and Aquatic Environments</td>
<td>UPVD</td>
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<tr>
<td></td>
<td></td>
<td>Water - speciality: Coast and Sea Management</td>
<td>UM3, UM2, UM1</td>
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<td></td>
<td>European Master Sustainable Development in Agriculture (AGRIS MUNDUS)</td>
<td>Montpellier SupAgro, 5 European universities</td>
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<tr>
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<td>Ingénieur (Engineering degree)</td>
<td>Risk Management and Environment</td>
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<td></td>
<td>Engineer in International Agri-Development</td>
<td>ISTOM</td>
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<tr>
<td></td>
<td></td>
<td>Chemistry and Bioprocessing for Sustainable Development (Green Chemistry – Sustainable Chemistry)</td>
<td>Montpellier SupAgro</td>
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<tr>
<td></td>
<td></td>
<td>Agronomy Engineer, “Water and Water Engineering” Major</td>
<td>AgroParisTech</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Agri ICT - Information &amp; Communication Technologies</td>
<td>Montpellier SupAgro</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Territories and Resources: Public Policy and Stakeholders</td>
<td>Montpellier SupAgro</td>
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<tr>
<td></td>
<td>Bac +6</td>
<td>Mastère spécialisé (Specialised MSc)</td>
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<tr>
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<td></td>
<td>Industrial Safety and Environment</td>
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<td></td>
<td>Bac +8</td>
<td>Doctorat (PhD)</td>
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<td>Integrated Systems in Biology, Agronomy, Geosciences, Hydrosciences, Environment (ED 477 SIBAGHE)</td>
<td>AgroParisTech, Montpellier SupAgro, UM1, UM2</td>
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<td>Territories, Time, Societies and Development (ED 80 TTSD)</td>
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<td>Sciences and AgriSciences (ED 536 SAS)</td>
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**Short non-degree programmes**

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<tr>
<th>Institution</th>
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<tbody>
<tr>
<td>AgroParisTech</td>
<td>Flood prevention and dynamic flood slowing structures (5 days)</td>
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<tr>
<td></td>
<td>Hydrosystems: hydromorphology, hydroecology, environmental assessment (4 days)</td>
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<td>Financial instruments to reinforce and develop water and sanitation services (4 days)</td>
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<td></td>
<td>Human resource management in water and sanitation services (4 days)</td>
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<tr>
<td></td>
<td>Strategic planning for water and sanitation services (12 days)</td>
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<td></td>
<td>Engineering of existing river embankments (5 days)</td>
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<tr>
<td></td>
<td>Water quality and health (4 days)</td>
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<tr>
<td></td>
<td>Principles and tools of water and sanitation services management (4 days)</td>
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<td></td>
<td>Greenways and blueways: land use planning tools (4 days)</td>
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<td></td>
<td>Preparation for the negotiation of a public service delegation contract for water or sanitation (4 days)</td>
</tr>
<tr>
<td>Montpellier SupAgro</td>
<td>Reuse of waste water for irrigation (21 hours)</td>
</tr>
<tr>
<td>UM2</td>
<td>DU Technician specialised in aquaculture</td>
</tr>
<tr>
<td></td>
<td>DU Project and Operations Manager in aquaculture and halieutics</td>
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</tbody>
</table>
Focus on some Master’s degrees centred on water

“Water” Master: a unique degree with five specialities

Thanks to its unique disciplinary diversity, Montpellier has one of the best research and higher education potentials in Europe in the field of water. The partner institutions in the city (UM1, UM2, UM3, Montpellier SupAgro, AgroParisTech, CIHEAM-IAMM) offer training programmes covering all aspects related to water. For the five specialities proposed in the “Water” Master, the final orientation of the student is chosen in the second year of master according to the type of internship: in a laboratory (research orientation) or in a company/organisation (professional orientation). The five specialities offered are:

- Water and agriculture
- Contaminants, water and health
- Water and society
- Water and coasts
- Water and resource (either HYDRE “Hydrology, Risk, Environment” pathway or H3E “Qualitative and Quantitative Hydrogeology, Environment” pathway).

The main openings after this degree programme lie in the following fields of activity: Water and Environmental Sciences; Regional Management; Public Policy; Consultancy, Mediation, Evaluation; Environmental Law, Insurance; Higher Education / Research; Water Supervision and Analysis; Ecotoxicological and Health Risks; Water Quality department in private or public structures; Agronomy.

Students are selected at the M1 level from applicants with a 3-year university degree or equivalent in different fields (sciences, geography, law, economics, health...). Enrolment in M2 is reserved in priority for students who have successfully completed the M1, then to applicants from other Master programmes, depending on availabilities and on prerequisites. Entry at the M1 or M2 level is also open to employees as part of a vocational training programme. ***
The Master “Hydrogeology, Soils and Environment” (HSE) is proposed in continuity with the educational programmes delivered at the Avignon University (UAPV) since the early 80s, in water sciences research and engineering. The aim of this Master is to train practitioners able to understand the water resource in its setting (impact of land use change on the resource) and in its relationship with the soil (quantitative and qualitative role of this interface and vulnerability with regard to pollution). To this end, the acquisition of knowledge is focused on three topics:

- Functioning of the non-saturated zone;
- Functioning of aquifers;
- Modelling.

Long-standing relationships with laboratories, research units and companies working in the water and environmental sectors have made it possible to put together a teaching team comprising 40% of the teachers from outside the UAPV: professionals from public water and environmental management organisations, engineering firms or companies specialised in the protection or exploitation of the water resource, as well as researchers from affiliated public bodies. In terms of research, the Master is linked to the EMMAH JRU, that is part of the UAPV “Sciences and Agrisciences” graduate school (see page 69). The HSE Master has both professional and research orientations. The pursuit of a Ph.D. thesis or entrance to the professional world depends on the type of internship chosen (in a research lab or in a professional organisation).

Students are selected at the M1 level after a bachelor’s degree in Earth Sciences or Environmental Sciences. They automatically integrate M2 if the M1 is successfully completed. Additional students may be recruited in M2. The second year of the Master is jointly accredited with the La Réunion University (UR). The partners from the UR’s Department of Earth Sciences are in charge of specific courses and participate in the supervision of internships.

In order to train and build the capacities of future managers of urban water and sanitation services in developing, emerging and transition countries, the “Water for All” chair proposes an international executive master's “Water for All”. This training programme (delivered in French and English) offers confirmed professionals in this sector tools, methods and technologies to:

- Drive changes in these services;
- Assess the technical, social and financial sustainability of their services;
- Elaborate strategies to improve them.

This 12-month training programme, delivered by the AgroParisTech centre in Montpellier, is based on an operational partnership with:

- The company that defines the mission of its auditor;
- The auditor that builds the action plan satisfying the defined mission;
- The training team, including professionals, which trains and supports the auditors throughout their mission in Montpellier during the teaching periods and back in their service to carry out their mission.

Moreover, to provide a better understanding of all the operational issues, this cooperative education programme alternates training periods in Montpellier with periods in the auditor’s organisation, plus an internship in an equivalent reference service in Europe.

The students are recruited at the 5-year post-graduate level, at the suggestion of their company or supervisory authority.
A doctoral programme lasts three years and involves producing and presenting laboratory research work. All students registering in a doctoral programme are attached to a graduate school. Graduate schools comprise research units or laboratories working on major sets of themes.

Their mission is two-fold: firstly, to ensure direct scientific support to the PhD students, and secondly, to provide additional training, such as seminars, scientific conferences or training modules throughout the 3 years. The aim of these modules is to improve the scientific education of the PhD students and to better prepare their professional future. Three graduate schools are concerned by the theme of water.

### Graduated Schools

**“Integrated Systems in Biology, Agronomy, Geosciences, Hydrosciences, Environment” Graduate School (SIBAGHE, ED477)**

The graduate school ED477 SIBAGHE (Integrated Systems in Biology, Agronomy, Geosciences, Hydrosciences, Environment) is part of UM2 in the Life and Earth Sciences section. It has a joint accreditation with Montpellier SupAgro, UM1 and AgroParisTech.

There are roughly 400 PhD students in the SIBAGHE graduate school, which has 40 affiliated research units, 450 approved research supervisors and several associated external research teams. Each PhD student in the SIBAGHE graduate school must successfully complete two scientific training modules and two professional modules. The graduate school manages thesis registrations, ensures PhD student supervision, verifies that the thesis charter is respected, and organises the thesis courses and professional guidance.

In the field of water, the graduate school hosts PhD candidates focusing their theses on the functioning of hydrosystems, water quality, use dynamics and resource and risk management. Both the quantitative and qualitative aspects are examined, sweeping through a large spectrum of disciplines ranging from hydrogeology to microbiology.

**“Territories, Time, Societies and Development” Graduate school (TTSD, ED60)**

The graduate school ED60 TTSD (Territories, Time, Societies and Development) is located at UM3. It encompasses 10 research centres from different institutes in Montpellier: UM3, UM1, Montpellier SupAgro, IRD, and École Nationale Supérieure d’Architecture de Montpellier (ENSA). TTSD gathers 65 research supervisors, 280 PhD students of which 32% are foreigners and offers PhD in 13 fields. Some of the main lines of research are:

- Rural areas, sustainable development, risk prevention and the conservation of natural areas;
- Relationships between societies (human groups, institutions, companies, etc.) and the environment (territories, resources, etc.);
- Physical characteristics and resources (natural or technological) of rural or urban areas, etc.

In the field of water, the graduate school hosts PhD candidates focusing their theses on governance and resource management, access to water and use conflicts, amongst others.

**“Sciences and Agri-Sciences” Graduate School (SAS, ED536)**

The graduate school ED536 SAS (Sciences and Agri-Sciences) encompasses research units in the field of “Sciences, Technology, Health” from the University of Avignon (UAPV) and INRA PACA (Provence-Alpes-Côte d’Azur). SAS thus federates research teams at the local level in complementary fields, linked to biology, physics, chemistry, mathematics, agrisciences, water and computing.

Its research potential is based on 15 recognised research units, gathering 151 teachers and researchers, of which 80 research supervisors. The geographic proximity of the research units making up the graduate school (university and INRA) and its interdisciplinary nature are essential to the school's ambitions.

In the field of water, the graduate school hosts Ph.D. candidates focusing their theses on the functioning of hydrosystems, plant ecophysiology, water quality, etc.
**List of acronyms and abbreviations**

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>AFEID</td>
<td>Association Française pour l’Étude de l’Irrigation et du Drainage</td>
</tr>
<tr>
<td>AISH</td>
<td>Association Internationale des Sciences Hydrologiques</td>
</tr>
<tr>
<td>AMESD</td>
<td>African Monitoring of Environment for Sustainable Development</td>
</tr>
<tr>
<td>ANR</td>
<td>Agence Nationale de la Recherche</td>
</tr>
<tr>
<td>ART-Dev</td>
<td>Acteurs, Ressources, Territoires pour le Développement</td>
</tr>
<tr>
<td>BRGM</td>
<td>Bureau des Ressources Géologiques et Minières</td>
</tr>
<tr>
<td>CEA</td>
<td>Commissariat à l’Énergie Atomique et aux Énergies Alternatives</td>
</tr>
<tr>
<td>CEFREM</td>
<td>Centre de Formation et de Recherche sur les Environnements Méditerranéens</td>
</tr>
<tr>
<td>CERTOP</td>
<td>Centre d’Étude et de Recherche Travail Organisation Pourvoir</td>
</tr>
<tr>
<td>CGIAR</td>
<td>Consultative Group on International Agricultural Research</td>
</tr>
<tr>
<td>CIHEAM</td>
<td>Centre International de Hautes Etudes Agronomiques Méditerranéennes</td>
</tr>
<tr>
<td>CID</td>
<td>Commission Internationale des Irrigations et du Drainage</td>
</tr>
<tr>
<td>CIRAD</td>
<td>Centre International de Recherche Agronomique pour le Développement</td>
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<tr>
<td>CNES</td>
<td>Centre National d’Etudes Spatiales</td>
</tr>
<tr>
<td>CNPQ</td>
<td>National Council for Scientific and Technological Development (CNPq)</td>
</tr>
<tr>
<td>CNRS</td>
<td>Centre National de la Recherche Scientifique</td>
</tr>
<tr>
<td>CPWF</td>
<td>Challenge Program on Water and Food</td>
</tr>
<tr>
<td>CRP5</td>
<td>CGIAR Research Programme 5</td>
</tr>
<tr>
<td>DPSIR</td>
<td>Driving forces, Pressures, State, Impacts, Responses</td>
</tr>
<tr>
<td>DU</td>
<td>Diplôme d‘Université</td>
</tr>
<tr>
<td>ECOSYM</td>
<td>Laboratoire écologie des systèmes marins côtiers</td>
</tr>
<tr>
<td>ED</td>
<td>École Doctorale</td>
</tr>
<tr>
<td>ELSA</td>
<td>Environmental Lifecycle &amp; Sustainability Assessment</td>
</tr>
<tr>
<td>EMA</td>
<td>École des Mines d’Alès</td>
</tr>
<tr>
<td>EMMAH</td>
<td>Environnement Méditerranéen et Modélisation des Agro-Hyrdosystèmes</td>
</tr>
<tr>
<td>ENSA</td>
<td>École Nationale Supérieure d’Architecture de Montpellier</td>
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<tr>
<td>ENSCM</td>
<td>École Nationale Supérieure de Chimie de Montpellier</td>
</tr>
<tr>
<td>EPLEFPA</td>
<td>Établissement Public Local d’Enseignement et de Formation Professionnelle Agricole</td>
</tr>
<tr>
<td>EPTB</td>
<td>Établissement Public Territorial de Bassin</td>
</tr>
<tr>
<td>ESPACE-DEV</td>
<td>Espace pour le Développement</td>
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<tr>
<td>FP7</td>
<td>European Union 7th Framework Programme</td>
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<tr>
<td>FRIEND</td>
<td>Flow Regimes From International and Experimental Network Data</td>
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<tr>
<td>FUI</td>
<td>Fond Unique Interministèriel</td>
</tr>
<tr>
<td>G-EAU</td>
<td>Gestion de l’Eau, Acteurs, Usages</td>
</tr>
<tr>
<td>GM</td>
<td>Géosciences Montpellier</td>
</tr>
<tr>
<td>GREED</td>
<td>Gouvernance, Risque, Environnement, Développement</td>
</tr>
<tr>
<td>GREEN</td>
<td>Gestion des RÉsources naturelles renouvelables et ENVironnement</td>
</tr>
<tr>
<td>HSM</td>
<td>HydroSciences Montpellier</td>
</tr>
<tr>
<td>IAHS</td>
<td>International Association of Hydrological Sciences</td>
</tr>
<tr>
<td>IAMM</td>
<td>Institut Agronomique Méditerranéen de Montpellier</td>
</tr>
<tr>
<td>ITCS</td>
<td>Information and Communication Technology Sciences</td>
</tr>
<tr>
<td>IEM</td>
<td>Institut Européen des Membranes</td>
</tr>
<tr>
<td>IFREMER</td>
<td>Institut Français de Recherche pour l’Exploitation de la Mer</td>
</tr>
<tr>
<td>INPT</td>
<td>Institut National Polytechnique de Toulouse</td>
</tr>
<tr>
<td>INRA</td>
<td>Institut National de la Recherche Agronomique</td>
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<tr>
<td>INSA</td>
<td>Institut National des Sciences Appliquées</td>
</tr>
<tr>
<td>INSU</td>
<td>Institut National des Sciences de l’Univers</td>
</tr>
<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
</tr>
<tr>
<td>IRD</td>
<td>Institut de Recherche pour le Développement</td>
</tr>
<tr>
<td>IRSTEA</td>
<td>Institut national de Recherche en Sciences et Technologies pour l’Environnement et l’Agriculture (former CEMAGREF)</td>
</tr>
<tr>
<td>ISTOM</td>
<td>École supérieure d’agro développement international</td>
</tr>
<tr>
<td>ITAP</td>
<td>Information – Technologie – Analyse environnementale–Procédés agricoles</td>
</tr>
<tr>
<td>IWM</td>
<td>International Water Management Institute</td>
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<tr>
<td>IWRA</td>
<td>International Water Resource Association</td>
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<tr>
<td>JRU</td>
<td>Joint Research Unit</td>
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<tr>
<td>LAMETA</td>
<td>Laboratoire Montpellierain d’Economie Théorique et Appliquée</td>
</tr>
<tr>
<td>LBE</td>
<td>Laboratoire de Biotecnologie de l’Environnement</td>
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<tr>
<td>LGEI</td>
<td>Laboratoire de Génie de l’Environnement Industriel</td>
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<tr>
<td>LCA</td>
<td>Life Cycle Assessment</td>
</tr>
<tr>
<td>LISAH</td>
<td>Laboratoire d’étude des Interactions Sol–Agrosystèmes–Hydrosystèmes</td>
</tr>
<tr>
<td>LR</td>
<td>Languedoc-Roussillon</td>
</tr>
<tr>
<td>LSBB</td>
<td>Laboratoire Souterrain Bas Bruit</td>
</tr>
<tr>
<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
</tr>
<tr>
<td>NGRI</td>
<td>National Geophysical Research Institute</td>
</tr>
<tr>
<td>NRE</td>
<td>Nouvelles Ressources et Economie</td>
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<tr>
<td>NSZ</td>
<td>Non Saturated Zone</td>
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<tr>
<td>OMERE</td>
<td>Observatoire Méditérranéen de l’Environnement Rural et de l’Eau</td>
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<tr>
<td>OREME</td>
<td>Observatoire de Recherche Méditérranéen de l’Environnement</td>
</tr>
<tr>
<td>PACA</td>
<td>Provence - Alpes - Côte d’Azur</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>Recherche et Développement</td>
</tr>
<tr>
<td>SCHAPI</td>
<td>Service Central d’Hydrométérologie et d’Appui à la Prévision des Inondations</td>
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<tr>
<td>SME</td>
<td>Small and Medium Enterprises</td>
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<tr>
<td>SMI</td>
<td>Small and Medium Industries</td>
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<tr>
<td>SOERE</td>
<td>Systèmes d’Observation et d’Expérimentation au long terme pour la Recherche en Environnement</td>
</tr>
<tr>
<td>TETIS</td>
<td>Territoires, Environnement, Télédétection et Information Spatiale</td>
</tr>
<tr>
<td>UAG</td>
<td>Université des Antilles et de la Guyane</td>
</tr>
<tr>
<td>UAPV</td>
<td>Université d’Aix en Provence et des Pays de Vaucluse</td>
</tr>
<tr>
<td>UMI</td>
<td>Université de Montpellier 1</td>
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<tr>
<td>UM2</td>
<td>Université de Montpellier 2</td>
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<tr>
<td>UMS</td>
<td>Université de Montpellier 3</td>
</tr>
<tr>
<td>UMR</td>
<td>Unité Mixte de Recherche</td>
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<tr>
<td>UMS</td>
<td>Unité Mixte de Service</td>
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<tr>
<td>UNESCO</td>
<td>United Nations Educational, Scientific and Cultural Organization</td>
</tr>
<tr>
<td>UNîmes</td>
<td>Université de Nîmes</td>
</tr>
<tr>
<td>UPR</td>
<td>Unité Propre de Recherche</td>
</tr>
<tr>
<td>UPS</td>
<td>Université Paul Sabatier (Toulouse)</td>
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<tr>
<td>UPVD</td>
<td>Université de Perpignan Via Domitia</td>
</tr>
<tr>
<td>UR</td>
<td>Université de la Réunion</td>
</tr>
<tr>
<td>US</td>
<td>Unité de Service</td>
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<tr>
<td>WDM</td>
<td>Water Demand Management</td>
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<tr>
<td>WFD</td>
<td>Water Framework Directive</td>
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<tr>
<td>WHO</td>
<td>World Health Organisation</td>
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This series is meant to boost the awareness of our different partners on the expertise and potential available within our scientific community, but also to facilitate contacts for the development of scientific and technical cooperation and exchange.

This series is a deliverable of Agropolis International that is produced within the scope of its mission to promote expertise of the scientific community.

Each Dossier is devoted to a broad scientific theme, and includes a clear overview that is a ready reference for all scientists, researchers, and decision-makers, and provides a comprehensive entry into the scientific literature. It is intended to provide a comprehensive overview of the state of the art in a given field, as well as to highlight emerging trends and future directions.

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